

## **CHAPTER 7**

### **HYDROGRAPHIC PRACTICE**

#### **1. INTRODUCTION**

The execution of a surveying operation, from its inception to the final submission of the results, is a continuous process, all parts of which must be methodically and meticulously carried out if full value is to be gained from it. The most accurate and carefully gathered data will be wasted if not processed carefully and collated and rendered in a clear and understandable manner.

All information must be gathered, validated, checked and rendered in a logical and uniform manner using clear unambiguous terms so that the data may be recovered and understood both immediately after the survey and in the future.

The use of sophisticated computer systems and instrumentation in all areas has not lessened the surveyor's responsibility. The need for rigorous quality management is as essential now as ever, but made the more difficult by the rapidly increasing volume and complexity of data gathered. The surveyor must understand the principles of the equipment he controls, be meticulous in ensuring that any data input are entirely correct and examine with care the data output before they are passed to the next stage. Only by these means will the data rendered be of the highest quality and be able to fulfil its needs until the task can be repeated perhaps decades, if not centuries, later.

There is no substitute for practical experience where theoretical knowledge can be turned into practical skills; time spent in the field gathering data under the guidance of an experienced hydrographic surveyor will highlight the many difficulties and complex problems that need to be overcome to ensure the final product meets the initial requirement. The use and applications, to which highly complex sophisticated equipment can be best applied, can only be learnt whilst involved in the practical tasks of a hydrographic survey.

The processes are discussed in more detail in the following sections. The points covered are not exhaustive, and the surveyor must use his judgement and experience to expand or contract the list as considered appropriate. This chapter will consider general principles applicable to any survey.

#### **2. HYDROGRAPHIC SURVEY PLANNING**

As will be seen, survey planning is a complex process requiring considerable attention to detail, a flexible approach, good management and effective decision-making. If the planning is thorough, the chances are that the survey will be good too.

##### **2.1 The Hydrographic Project**

Survey planning is the term used to cover the whole process of the development of a hydrographic project from its inception, its subsequent issue to a designated unit, the detailed planning within that unit of how to conduct the survey, and the final submission of data to the Hydrographic Office.

Survey planning must, therefore, involve a coherent procedure which will consist of the following stages:

- a. survey requirement.
- b. preparation of a hydrographic survey specification. (To include a review of existing data.)

- c. issue to a designated unit.
- d. programme planning of that unit.
- e. assessment of the task within that unit.
- f. reconnaissance requirements.
- g. resource allocation.
- h. detailed survey planning.
- i. estimation of time required.
- j. final programme planning and approval.
- k. liaison with outside authorities.
- l. administration planning.
- m. daily planning.
- n. plans for compilation and checking of data.
- o. plans for rendering of data.

The development of the survey requirement varies greatly from country to country. The final survey specification is assigned to a designated survey unit which has responsibility for the remaining planning requirements. A 'designated unit' might be a government-surveying vessel, an independent survey party working either in a chartered vessel or using boats, or a commercial company working under contract. Each nation will have its own planning process.

## **2.2 Assessment of the Survey Task**

Before detailed planning can take place, the surveyor must be very clear about the aim of the survey, and who will be the primary user of the information. In general every survey should cover the immediate needs of the user as well as benefiting others.

Having studied the survey requirement, accompanying data and graphics of the area to be surveyed, the surveyor must first decide whether any additional data is required and propose any changes he considers necessary to the survey task.

Once all the basic data is held and the limits and scale of the survey have been fixed, the main surveying tasks can be established. The specifications for the survey will be stated directly in the survey job specification, key amongst these should be the specified Order of the survey as defined IHO Publication S-44.

The main task assessment points are as follows:

- a. establishment of geodetic control;
- b. method of positional control and calibration of nav aids;
- c. sounding criteria including interlining policy;
- d. sonar search category;
- e. tidal datum and observations;
- f. wrecks and obstructions;
- g. seabed sampling;
- h. oceanographic observations;
- i. tidal stream observations;
- j. geophysical observations;
- k. coastline and topography;
- l. lights and buoys;

- m. sailing directions and views;
- n. radio Signals;
- o. ancillary observations (vertical photography, overfalls, measured distances, leading lines, shore magnetics, natural phenomena, etc);
- p. passage observations.

**Existing Data.** The surveyor should be provided with copies of the largest scale published chart and all previous surveys to survey scale, together with their Reports of Survey (RoS). These should be studied carefully, together with the relevant sections of tidal data, sailing directions, aerial photographs and topographic maps.

**Resource Allocation.** From the list of points in 2.2.5, and a study of previous data, the size of the task can be assessed. Detailed planning will take place after this process, but the initial study will reveal what resources are required to meet the task. The following list shows some of the considerations that should be made when planning resources:

- Weather predictions and sea state. These will affect the size of the vessel to be used for the task and the ability to use boats for inshore work and examinations.
- Size of the shallow water area. This will dictate how much boatwork is required. If boats are necessary, the time taken to complete the task will be highly dependent on sea state; 2.2.7.1 and 2 should, therefore, be considered together.
- Use of helicopters. It may be that the unit has a helicopter available, but if not is one required for access to remote sites?
- Logistics. The endurance of the surveyor's own resources will dictate fuel, water and stores requirements. Maintenance of equipment is another consideration.
- Manpower. The number and specialisation of personnel required to meet each task must be assessed. The following factors are also relevant: changes of personnel; mail and communications; leave and recreation; medical facilities ashore and afloat; shore support and transport; shore accommodation and monetary arrangements.
- Topography. This will dictate the resources required to access sites ashore.
- Detached Boat Camps - A detached boat camp may be ordered by survey specification in which case the planning list above should be followed. However, consideration should be given to detaching a boat to conduct inshore work and shoal investigations if a suitable harbour or sheltered mooring exists. Time spent lowering and hoisting boats is unproductive.

Likely constraints on the conduct of the survey should also be investigated. Investigate what fishing activity is likely to affect survey progress together with the constraints imposed by danger, firing and practice areas, shipping lanes and marine traffic choke points.

A field reconnaissance may be required to expedite the survey. See Section 3

### **2.3 Detailed Survey Planning**

Once the size and scope of the task has been assessed and the necessary resources required to conduct it decided upon, detailed survey planning can begin. A number of activities can be planned to run in parallel and a good surveyor will try to reduce the overall time required to achieve the aim. A comprehensive list of required actions is given in the following paragraphs, but it must be remembered that every survey will be different and additional items may have to be inserted, or listed ones deleted.

### **2.4 Horizontal Control**

The survey specification will detail the horizontal reference for the survey and list details of existing co-ordinated geodetic stations together with their descriptions if held:

Decide how best to achieve the accuracy standards of horizontal control set out in survey specifications. The survey specification will detail the choice of navaid, more than one may be ordered. In rare cases, it may not be possible to achieve the stated standards with the navaids available and relaxations may have to be sought from the Hydrographic Office.

Once the choice of navaids has been determined, their sites need to be chosen. Use whatever network analysis systems are available. Decide how best to co-ordinate new stations. Consider access to sites and any reconnaissance requirement. Decide how to power navaids and work out how often site replenishment will be required. Note the authorities that must be approached for permission to use the chosen sites, authorise frequency clearance and land boats and helicopters. This will include sites for shore marks if visual fixing methods are to be employed.

Decide on how and where the chosen navaids will be calibrated and whether re-calibration will be necessary during the course of the survey.

Most modern surveys use some form of GPS for control ashore and afloat. Where DGPS is used for control afloat it must be validated. In remote locations ashore, point positioning within 20cms should be achievable within 24 hours of data capture if data can be transmitted to the Hydrographic Office for comparison with the nearest ITRF monitoring site. Otherwise establishing a new station will require connection to an existing network.

### **2.5 Vertical control**

The survey specification will detail the datum to which soundings are to be reduced and its relation to existing land datums, a list of any existing benchmarks should also be provided. The following planning points should be considered:

Decide where to observe tidal heights if not ordered in the survey specification. Decide on the siting of additional poles and gauges if required and plan the laying and recovery of offshore gauges if appropriate. Ensure that gauge and pole sites do not dry out at low water, plan additional gauges and poles if this is unavoidable.

Decide how best to establish chart datum on the pole/gauge from existing benchmarks or from transfer of datum or observation and analysis. Plan to connect a newly established datum to a land based levelling system if applicable.

Establish the nature of the tide and expected ranges, and the affect this will have on fieldwork. Where there is a possibility of tide poles or gauges drying out an additional pole or gauges should be planned to allow tidal data to be recorded throughout the survey.

Decide whether co-tidal adjustments will be necessary. If they are, determine the tidal factors from tide tables and the appropriate co-tidal chart, or locally produce them from the best data available. Seek advice from the Hydrographic Office if necessary.

## **2.6 Tidal Streams**

Establish the expected maximum rate and direction of tidal stream within the survey area.

Determine the requirement for full tidal stream observations and how online observations can be conducted.

Identify charted overfalls, eddies and freshwater springs and plan to observe them.

## **2.7 Sounding**

The following general considerations should be taken into account when conducting initial planning:

By examining the largest scale charts of survey area and previous surveys locate all critical or controlling depths and prepare sounding comparison overlay.

Plan main survey line spacing, direction and sounding speed. For SBES, where possible, lines should be perpendicular to general direction of contours.

Plan cross line direction, normally at right angles to main sonar and sound line direction, and plan to run these at the start of the survey as a crucial quality control measure.

Estimate likely spatial or temporal changes in sound velocity regime and plan initial sound velocity probe coverage.

Estimate sounding error budget and compare to the survey specification.

Vessel speed is to be assessed for the expected range of depths in the survey area and the type of echo sounder in use. Compare vessel speed with speed required for towing sonar to determine optimum and maximum survey speed.

During the planning of sonar and sounding lines, a list of all planned lines should be kept.

For SBES surveys additional lines should be considered inside the 10m contour. Additional lines should be run parallel to a jetty or wharf.

Lines of sounding should be planned and run along recommended tracks, leading lines, in possible anchorages and off headlands passed close to hand by vessels on normal passage.

If using SBES for offshore surveys particular attention should be paid to the sounding of depths <40m, where the least depth should be obtained over all seabed features. Interlines should be run in depths <40m unless the seabed is flat and featureless and no dangers are shown to exist by complete coverage by high definition towed side scan sonar. A full explanation should be given in the RoS when areas <40m are not interlined.

## **2.8 Side Scan Sonar**

The following general considerations should be taken into account when conducting initial planning:

Tidal stream will have a significant influence over sonar line direction when using towed systems, often a compromise will need to be reached between the best sounding and sonar line directions. In some cases bathymetric and sonar data will have to be gathered separately.

Inspect the Wreck List supplied with the survey specification data and identify those with positions listed as approximate and thus requiring disproving searches or special attention. The limit of the area of this search may extend outside the given limits of the stated survey area. See IHO Publication S-44 Chapter 6.

Plot Wreck List information, other dangers and depth contours on planned track plots.

When surveying in or near oilfields or exploration areas careful note is to be taken of 500 metre safety zones, seabed installations and possible pipelaying operations to ensure the safety of the sonar towfish.

Sonar lines should be planned to run within 20 degrees of the prevailing tidal stream or current. In areas of strong tidal flow, a direction much less than 20 degrees may have to be adopted to ensure that the sonar towfish follows the ship's track closely.

The sonar line spacing should be planned in accordance with the survey requirements.

Ensure that any disproving search areas lying on the outer edge of the survey area are covered. Additional lines are to be planned to run outside the area in order to ensure complete ensonification of the area, with appropriate overlap.

Whenever a survey includes a channel, recommended track or leading line in restricted waters it should be swept by sonar. When planning such sweeps allowance should be made to accommodate the largest vessels likely to use these tracks paying particular attention to turning areas and where a track changes course.

## **2.9 Seabed Sampling**

Seabed samples should be obtained as required throughout the entire survey area. See IHO Publication S-44 4.2.

The survey specification may require the retention of a percentage of all samples obtained. Due allowance should be made for this requirement.

## 2.10 Coastline Delineation, Conspicuous Objects and Topography

The requirement for mapping of the coastline and other topography will be defined in the survey specification.

The High Water line shown on maps cannot always be relied upon as the coastline for hydrographic surveys.

Using charts and any photo plots supplied with the survey specification, identify those areas adequately covered and those requiring additional work. Where no modern charts, maps or air photo plots exist, all coastline and topographic detail which will be of use to the mariner should be fixed accurately.

The surveyor should attempt to obtain copies of any relevant local modern charts, maps and geodetic data additional to those supplied with the survey specification. Any such data should be rendered to the Hydrographic Office at the end of the survey.

Determine the means of delineating inadequate areas and identify equipment to be used to define such areas appropriate to the scale of the survey.

## 2.11 Ancillary Observations

**Geophysical Observations** The survey specification should detail which geophysical observations are required, but generally magnetic and gravity observations can be taken concurrently with bathymetry. The survey specification will cover line spacing in detail. If magnetic anomalies are charted, plan to observe and report them. Plan magnetic observations ashore if ordered in the survey specification.

### Lights and Buoys

Establish which lights should be visible from the survey ground and plan to check their characteristics.

Establish the number of buoys that require to be fixed.

**Air Photography** If air photography is ordered, then plan to fly it during advantageous tidal and weather conditions. The subsequent photographs may be used for coastlining and topography.

**Sailing Directions and Views** The amendments to Sailing Directions can normally be compiled during the course of the survey and additional time to observe information for inclusion should not be required. Plan to check all existing photographic views and to photograph new ones as ordered in the survey specification. Plan to check harbour facilities and the facilities for small craft.

**Radio Stations** Plan to check the accuracy of published data.

**Jetties, Wharves and Landing Stages** Plan to check the details of jetties, wharves and landing stages. This can normally be done during boat sounding operations.

## 2.12 Surveying Team Organization

The senior surveyor will normally prepare a Survey Order Book which will give an overall plan, stating how the survey is to be tackled, and detailing responsibilities for planning and execution of the work. These orders should be updated regularly to inform the whole team of the short term priorities and to give the framework within which more detailed day-to-day planning can be made. When both the ship and her

survey boats are working together on a daily basis the activity becomes particularly intensive and complicated. It will then be vital to have a flexible and well thought out plan to co-ordinate times of boat lowering/hoisting, change of boat's crews, provision of victuals, and instructions for those in charge of boat work.

Shortage of manpower will always be a problem at the start of the survey, with observing and tidal parties away simultaneously and boats crews and shore parties on standby to land nav aids etc. Good shore transport and/or helicopters will greatly assist the successful start of a survey.

The Bridge and Chartroom organisations require careful planning and structuring ensuring that the data is acquired and handled in the most efficient manner.

The pressure on all surveying units for increased productivity is considerable. Good management and planning as well as positive leadership is fundamental to the success of the survey.

### **2.13 Compilation and Checking of Data**

Quality Control should be built into the plan at every stage, with nominated checkers of all data required to keep abreast of the incoming work.

Plan the allocation of drawing and compilation tasks. Ensure that accompanying fair records are compiled and checked as the survey progresses.

In a large survey, it is generally better to complete one area in all respects before moving to the next. This will ensure that complete data can be rendered should the unit be withdrawn from the survey for some over-riding reason.

It may be convenient to allocate the writing of separate sections and annexes of the Report of Survey to individuals.

All transcripts and records should be compiled as the survey progresses and not left until afterwards if at all possible.

The comparison of surveyed data with previous surveys is a most important consideration; it should proceed with the fieldwork and the planning should take account of additional investigation and disproving searches that may arise from differences between charted and surveyed data.

### **2.14 Data Rendering Requirements**

The data required to be rendered to the Hydrographic office will vary greatly depending on national policy and requirements. In general it will include:

- a. bathymetric data set in digital or graphic (Fair Sheet) format;
- b. navigational track data in digital or graphic format;
- c. sonar data set in digital or graphic format;
- d. seabed texture data set in digital or graphic format;
- e. report of survey.



Hydrographic Offices should appraise all the survey data rendered and dispatch a critique within two months of rendering the data. Points raised from the Hydrographic Office should be answered as quickly as possible while the survey is still fresh in the mind.

## **2.15 Operation programme Development**

The total number of planned days taken to complete a survey must now be fitted into the requirements for port calls, vessel maintenance, passage time, exercises etc. Each vessel will have its own operating cycle and from this skeleton a work cycle can be fleshed out and passed for approval if necessary. If the estimation of time required shows that the survey cannot be conducted within the broad timescale allotted in the survey specification the matter must be represented for programme modification or reduction of the size of the survey task.

## **2.16 Operation Duration and Cost Estimates**

There are no hard and fast rules for arriving at a precise time required for completing a survey. An experienced surveyor can sum up the requirement after studying the survey specification and arrive at a good estimate without recourse to a mathematical sum. However, the format provided at Appendix 1 to this chapter will provide a reasonable answer and can be adjusted to suit the needs of any survey. During the detailed planning stage the surveyor should maintain a tote of line mileage, numbers of wrecks, numbers of bottom samples required etc. This data can then be used to compile the time required format.

## **2.17 Liaison with Outside Authorities**

As soon as the survey specification is received, letters should be sent to a number of outside authorities giving the broad details of the survey specification and the timescale of the survey, together with a request to use facilities if appropriate. This can be followed by further letters with more detail once the detailed planning has been conducted, if considered necessary. A list of examples is shown below. Survey specifications are often sent to a number of agencies direct from the Hydrographic Office, and the survey specification covering letter should indicate those organisations that have already been informed:

- a. fishing authorities;
- b. local landowners;
- c. coastguards;
- d. lighthouse authorities;
- e. local defence forces;
- f. firing or exercise range operating authorities;
- g. oilfield operating authorities;
- h. local government representatives;
- i. naval attachés;
- j. local chart/land survey departments;
- k. helicopter operating authorities;
- l. religious authorities.

In addition, if a detached boat party is to be landed or shore parties are to be landed from sea or operate from a local port or settlement, the following should also be considered:

- a. local police;
- b. Mayor, Town Chief or Headman;
- c. harbour authorities;
- d. local Service establishments.

Follow up visits may need to be made during either the advanced survey reconnaissance or on arrival. Security implications should always be considered.

### **3. SURVEY RECONNAISSANCE**

#### **3.1 General Reconnaissance**

Reconnaissance is needed prior to any survey to acquire the necessary data to permit the best and most economical survey to be carried out. The information collected should cater for the design, planning, organisation and observations of the proposed task. The reconnaissance may be carried out immediately before the survey, or many months in advance.

The reconnaissance is important; a bad one can result in wasted time and effort later, when much more expensive assets are likely to be involved. It should also be complete because a poor reconnaissance will inevitably result in a poor plan.

The surveyor called upon to do the reconnaissance should possess experience, commonsense, a sound knowledge of all equipment available, and have no preconceived ideas about the method by which the task will be carried out. The actual observations can safely be left to less experienced surveyors once the major decisions have been taken.

#### **3.2 The Geodetic Reconnaissance**

The purposes of the reconnaissance can be summarised as follows:

- a. establish local contacts in person;
- b. visit all proposed stations - select actual sites. Recover existing control stations;
- c. confirm inter-visibility;
- d. decide upon final network design (re-analyse if necessary);
- e. permanently mark geodetic stations;
- f. describe geodetic stations;
- g. prove the proposed observing plan (instruments/targets required). Prepare detailed observing programme;
- h. prove the administrative plan for the main survey, amend as necessary.

For each new geodetic station, the following information will be required:

- a. accessibility by road, rail, boat, foot or helicopter. Time for access (e.g. on foot from road) and recommended route;
- b. visibility from station and requirements for any subsequent clearing;
- c. description of the station, magnetic bearings to other visible stations;
- d. photographs of the station, surroundings, and panoramic photos from the station;
- e. local factors, customs etc;
- f. likely visibility and meteorological conditions.

### 3.3 The Tidal Reconnaissance

Whenever possible it is advisable to use established or previously used tide stations for commonality of data. When selecting a site for a tide gauge and tide pole the following must be considered:

- Ease of Erection Consider which is the easiest place to erect a tide pole and gauge, some places are easier than others, and some places are impossible;
- The Station Must Not Dry Out. The zero of the Tide Pole and Tide Gauge pressure sensor should not dry out. If this is unavoidable a secondary pole and gauge should be established below the level of the first gauge or pole;
- Ease of Reading. The pole or gauge must be sited such that it can be read at all times;
- Security. Avoid situations where the tide pole and particularly the tide gauge will be likely to be interfered with by the public, e.g. Fishing boats berthing;
- Shelter. The pole or gauge sensor should be sited away from the more severe effects of weather sea and swell;
- Protection. Ideally the tide gauge recorder should be placed in a lockable building;
- Impounded Water. Water that is restricted in movement by a sandbar or basin will not be at the same level as the open sea. Therefore a station should be selected that reflects the true level of the sea at the survey area;
- Proximity of Bench Marks. Select a station near to two benchmarks if possible, to avoid time spent on long levelling runs;
- Accessibility. If a tide watcher is employed, accommodation should be close at hand. If a detached Boat Party is in operation the tide station should be close to where the boat is moored, or close to the tide party base.

## 4. DATA ACQUISITION

The depths shown on a nautical chart are its most important feature and the mariner must be able to rely implicitly on accurate bathymetry to avoid danger. The greatest care must be taken to ensure that soundings are precisely positioned. An error in position is often more misleading than an error in depth, for a mariner is more likely to navigate clear of a charted danger than to rely on the accuracy of its charted depth and deliberately navigate over it.

The disciplines of sounding error monitoring, data checking and Quality Control (QC) are continuous procedures that need to be sustained throughout the entire hydrographic surveying process. Similarly the generation of the final report should commence on completion of the planning stage and be uninterrupted during the remaining phases of the survey; it should not be left until the end when all data acquisition has been completed.

## 4.1 Horizontal Control and Calibration

### 4.1.1 Introduction

The Hydrographic Specification will detail the horizontal datum to be used during the survey; if, after the planning and reconnaissance (paragraph 2.4), there are insufficient co-ordinated geodetic stations, secondary stations, landmark and navaids then additional horizontal control should be generated within the area and sub-areas to meet the required accuracies for positioning at sea.

The methods selected for providing control offshore will dictate to a great extent the preparatory work required onshore. Numerous shore stations may be needed for visual fixing in surveys of small areas close inshore, whereas only two stations may be required for surveys controlled by local area DGPS. In either case, the stations should be as close to the high water line as possible to avoid inaccuracies in the electromagnetic patterns caused by variable propagation conditions over land paths.

Satellite position fixing is capable of achieving great accuracies with GPS Relative Positioning Techniques – code phase Differential GPS (DGPS) and Real Time Kinematic (RTK) carrier phase DGPS – with only one GPS reference station, which gives greater flexibility on site selection and deployment than is the case with terrestrial methods. DGPS corrections can be obtained from Radio Beacon Navigation Service (Beacon-IALA) and a variety of WAAS (Wide Area Augmentation Systems) via commercial services (Landstar, Seastar, Omnistar, Skyfix etc.) and free service (EGNOS); these systems provide good accuracies in positioning without the need for a reference station onshore, however GPS receiver calibrations and real time checks on geometry (GDOP) should be conducted during the survey.

### 4.1.2 Horizontal Control Ashore

Control for offshore surveys can usually be generated by extending the established geodetic network in the vicinity. Failing this it will be necessary to determine a datum position, azimuth and scale to allow the new stations to be fixed relative to each other.

Conventional land surveying techniques should be employed, these are summarized below, detailed explanations can be found in Chapter 2 with reference texts listed in the bibliography:

- a. the determination of absolute position of a datum point (A);
- b. the orientation of the network by azimuth observations (at A to B);
- c. the determination of scale by baseline measurement (from A to B);
- d. the extension of the network by traverse, triangulation or trilateration to the required stations, with intermediate stations fixed by resection or intersection.

Operations a., b. and c. will be required only where no established geodetic network exists. This is rarely necessary; the techniques for astronomical or satellite GPS observations ashore, performed for geodetic surveys, are beyond the scope of this manual.

Angular observations are made by theodolite or sextant with distance measured by mechanical, optical or electromagnetic (EDM) means or both by Total Stations. Subsequent computations may be carried out on the reference spheroid in terms of latitude and longitude, or on the grid and projection in rectangular co-ordinates using plane trigonometry.

GPS observations, carried out using geodetic dual frequency receivers or by RTK DGPS technique, can produce better accuracies in the determination of a baseline (see paragraph 6.1 Chapter 2), however it should be remembered that the position co-ordinates obtained are referred to the WGS 84 ellipsoid and a

compatible grid and projection. Datum transformation from WGS 84 must be performed (see paragraph 2.2.3 Chapter 2), if the hydrographic survey is to be conducted in a local horizontal and vertical datum.

The positional accuracies of marks for primary shore control points and secondary stations are specified in IHO S-44.

### **4.1.3 Horizontal Control at Sea**

#### **General Description of Positioning Systems**

Terrestrial positioning methods include traditional land-based techniques such as:

- a. sextant resection positioning;
- b. triangulation/intersection positioning;
- c. visual positioning methods;
- d. tag line positioning methods;
- e. range-azimuth positioning methods;
- f. land based electronic positioning systems.

Since the early 1990's most of these terrestrial positioning methods have been largely replaced by satellite-based positioning systems, namely GPS and more accurate code phase Differential GPS (DGPS) and Real Time Kinematic (RTK) carrier phase DGPS. Within isolated project areas, where satellite GPS methods may be inaccessible or impractical, one of the traditional terrestrial survey techniques may be needed to provide survey control. Examples of such cases may include:

- a. small dredging or marine construction projects where only a limited amount of depth coverage is required;
- b. areas under bridges, in deep-draft harbour berths or near dams where GPS satellite view is masked;
- c. intermittent, low-budget projects where traditional terrestrial positioning techniques may prove more economical than equipping a fully automated DGPS-based hydrographic survey system;
- d. quick reconnaissance surveys, where meeting a specific positional accuracy standard is not required.

Procedural methods and Quality Control (QC) criteria for some of these terrestrial survey techniques are detailed in this manual primarily for reference purposes.

#### **Horizontal Positional Accuracy**

All the positioning methods, summarized at Appendix 2 in Table 7.1 “Horizontal Positioning Systems and Selection Criteria”, are capable of meeting the required minimum standards of horizontal accuracy for a selected survey Order, detailed in IHO S-44, provided that distances from the shore-based reference point and the vessel are within normal system operating limits. The operating limits vary with the type of positioning system, procedures employed and the environment in which it is being used. In general, the positional accuracy of all systems will degrade as a function of distance from the baseline reference points, some faster than others. Users must fully assess and evaluate the resultant accuracy of any positioning method, including DGPS, to ensure its suitability for the survey to be undertaken.

## **Selection of Positioning Systems**

The accuracies predicted for positioning systems employed in hydrography are generally quoted with reference to normal use of the equipment within their operational limits and the different classes of surveys. Table 7.1 shows the criteria for selection and employment against the orders of hydrographic surveys, as defined in the IHO S-44, for positioning systems with their anticipated positional accuracy. Suitability of a particular technique for a survey should be guided by the tasking authority taking these limitations into account. The Table assumes a standard project area located within 25 miles of the coastline or shoreline reference point (horizontal control) or up to 200 meters water depth. Criteria for performing surveys within these ranges should conform to the standards contained in IHO S-44 and in this Manual.

Generalised accuracy ranges achievable with each type of system are also shown in this and other manuals, including operators' equipment manuals; the extreme variations are a result of factors discussed elsewhere in this manual and relevant chapters of the above mentioned equipment manuals. The indicated maximum accuracy range is generally that which could be expected with the equipment being employed within its normal operating limits and conditions. In some cases the accuracy range covers those prescribed for Special, 1<sup>st</sup> and 2<sup>nd</sup> Order surveys; this indicates that project-dependent factors (geometry, distance offshore, etc.) must be considered in order to select the most appropriate equipment for a particular order of survey or project site.

### **Track Control**

The methods highlighted in paragraph 4.1.3.2 will prove the surveyor with a position at sea, in addition, he must ensure that his vessel follows the desired track over the seabed making correct allowance for effects of tidal streams, currents and wind drift and therefore thought must be given to this requirement when planning positional control. The chosen fixing method will often also provide track information, such as a left/right indicator displayed on a device of positioning system or on the monitor of special HW/SW automated data acquisition and control, however, particularly in close range work, supplementary aids must sometimes be provided for the steering of the vessel.

In traditional visual methods or old EPS techniques, a real time plot of the vessel's track is kept manually or by a track plotter with the survey data superimposed after reduction in the post processing stage. In this case plotting sheets should be prepared with collector overlays to be used to generate a running record of survey progress.

Whatever method is employed, it will have an impact on the planning and execution of survey and must be considered within the overall plan from the outset.

### **4.1.4 Field Preparation**

#### **General Description**

A field reconnaissance of the survey area will save considerable time during the data gathering stage of the task. The positions selected for survey marks should be visited, their suitability confirmed and descriptions written. Once the survey team arrives on site, equipment will need to be installed ashore and in the vessel, all of which may require field calibration and checking.

Working within the "strategic" framework drawn up at the Hydrographic Office, the surveyor-in-charge must refine the plan and if necessary review the deployment of personnel and equipment for optimum utilisation within the overall project. Any adjustments to the initially agreed plan should be discussed

with the Hydrographic Office and suitable methods for monitoring progress and achievement of key milestones should be put in place.

### **Observation Planning**

The greatest care should always be taken when observing the framework of the geodetic system, every opportunity taken to obtain checks on the observations and to detect weakness in observing techniques, observers and equipment. All calculations must be completed and very fully checked before proceeding with the fieldwork dependent on the accuracy of co-ordinates derived from such primary observations.

The surveyor should identify the optimum observing periods, using a mission planning program, to achieve the order of standard for the survey. Instrument selection should be such that observations of the appropriate type and standard are obtained, calibration data should be checked and the details recorded for inclusion in the Report of Survey.

### **Site Selection**

Considerable care should be taken on network creation, site selection and density, installation of the reference stations and the techniques for measurement of angles and distances, to ensure the necessary accuracy in the positioning to meet the survey Order. The type of survey being undertaken (harbour and approach, littoral, coastal or off-shore), the selected positioning system (visual /EDM/EPS/Satellite), the number of the LOPs and their geometry within the survey area will all have an influence on the final decision.

The site selection should be based on:

- a. accessibility of the site by land or from sea;
- b. the ability to occupy the station or the necessity to create an eccentric station;
- c. proximity to the shore or coastline with clear views to seaward;
- d. inter-visibility to adjacent sites, clear of structures likely to cause interference of EDM/EPS signals and unobstructed receipt of the satellite signals;
- e. availability of mains power or space to co-locate portable power supplies, such as batteries/solar panels and generators;
- f. site security and ability to leave equipment untended;
- g. site elevation and suitability for chosen positioning system.

### **Beacon Deployment and Inspection**

Check lists, created by the surveyor-in-charge from the equipment manuals, should be followed during the installation of the ground reference stations (EPS, DGPS or RTK GPS) or during the use of visual/EDM tools for measuring angles/distances (sextant, theodolite, EDM, total station) to ensure the correct operation of the system and similar techniques are used throughout the survey.

The type of the deployed ground reference stations (EPS, DGPS or RTK GPS) will determine the frequency of inspection necessary to verify correct operation; this is also the case for unmonitored total stations operating in automatic mode.

### 4.1.5 Alignment and Calibration of Positioning Systems

#### General Description

The type of system or tool selected will dictate the procedure adopted to verify performance against the anticipated limits to ensure the achieved positional accuracy matches the select survey Order requirements, as expressed in Table 7.1.

The alignment/calibration procedures and techniques, detailed in the user manual (or operator manual), should always be followed at the beginning and end of a survey and when deemed necessary to verify system performance in the field, particularly if performance or accuracy is suspect. These checks should be conducted, as far as possible, within the survey area at the expected ranges and against a previously calibrated higher order system or navigational aid or between co-ordinated control stations. All total stations, EDM systems and prisms used for primary control work should be serviced regularly, checked frequently over lines of known length and in date for periodic factory calibration.

#### Angular Measurement

Care should be taken to ensure that the correct observing techniques for angular measurement systems (sextants, theodolites, total stations) are used and that instruments are set up to minimise errors. Instruments should be in-date for calibrations and service; standard zeros for the appropriate order of observations should always be used and careful recording techniques to avoid blunders.

Each station selected for use should be visited and carefully checked against the station description, the distances to fixed reference points should be confirmed to determine if the station mark has been displaced. New stations should be checked for inter-visibility to the survey area and other stations and be linked to 3 established stations. The use of eccentric stations should be avoided whenever possible. Any amendments to the planned observing scheme due to unsuitability of the sites should be re-analysed to ensure that the standard for the order of survey is being met. All stations used should be marked and full descriptions recorded before observing at or to them.

When determining heights by angular measurement reciprocal heighting is to be used whenever possible. Before moving the observing instrument, verify the data recorded to ensure the observations, both angular and distance, are to the standard required, if the standards are not met, re-observe the entire set of observations.

The verified final angular and distance observations should be adjusted to the grid as appropriate for each type of observation by using an approved computer program and then compute the most probable position and error ellipse data. The error ellipse of each new station position should be carefully examined to determine the quality of the final position. Network analysis should be conducted.

#### Distance Measurement

When using distance measuring systems (EDM, EODM, total stations, etc.), all the procedures described in the operator/equipment manuals should be followed and a comparison check conducted against a geodetic baseline or a higher order system with greater or equal accuracy to that required by the order of survey for establishing position.



## **2D Measurement**

As with distance measuring systems, the guidance in the user/equipment manuals should be followed for 2D positioning systems with appropriate calibration and comparison checks conducted against higher order systems or geodetic baselines/networks.

When planning the use of microwave EPF systems to validate GPS positional data prior to the commencement of survey operations, care should be taken to ensure that established stations are all on a common datum. Navigation systems should be calibrated and verified by comparison with an alternative precise positioning system at the start of each survey and a validation undertaken at the end.

## **Satellite Measurement (3D)**

When using GPS satellite systems, observing procedures articulated by the Hydrographic Office and detailed in the user guides should be followed with great care to ensure the equipment is operated to its maximum capability for the various modes of positioning SPS, PPS, Differential and RTK available. All systems should be verified prior to fieldwork and a closing validation conducted on completion of observing secessions against a geodetic baseline, high order geodetic control net or a system with greater or equal accuracy to that required by the order of survey.

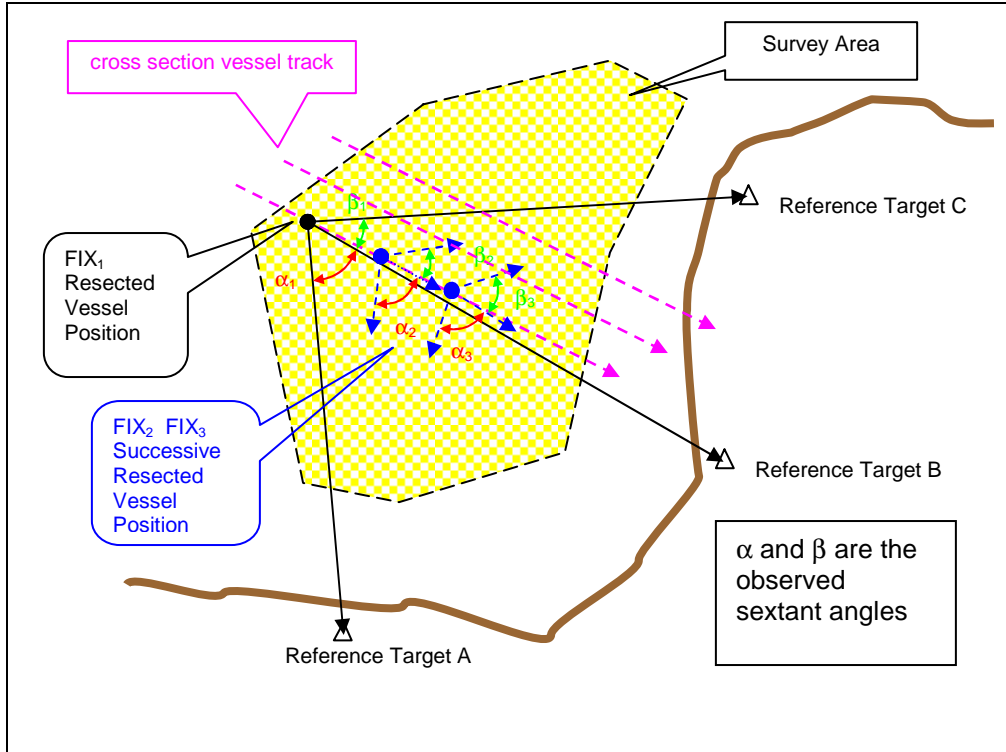
### **4.1.6 Horizontal Control Methods and Equipment**

#### **4.1.6.1 Sextant Resection Positioning**

##### **General Description**

Sextant positioning involves the simultaneous observation of two horizontal angles between three known objects from which the position of an offshore point is resected (see Figure 7.1). Sextant positioning is totally performed aboard the survey vessel and does not depend on electronics, communications, or shore-based support. Under certain conditions (i.e., close to targets or for near static position fixes) it can be relatively accurate when properly conducted by an experienced team. In general, however, sextant positioning under dynamic vessel conditions is no longer considered accurate for most applications.

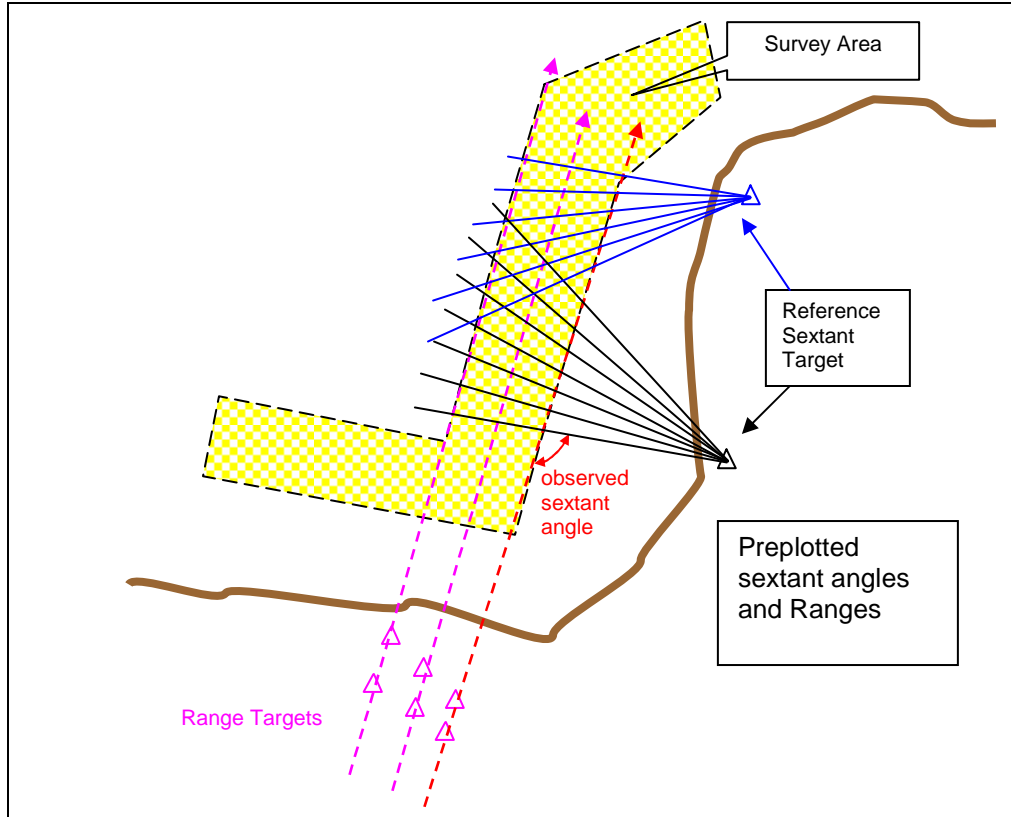
Hydrographic marks for sextant-controlled surveys may be located by sextant fixes or by sextant cuts. Lower than third-order traverse methods may be used, if the distance from a basic or supplemental control station does not exceed 4 km for hydrographic surveys at scales of less than 1: 10,000 or 2 km for larger scale surveys.



**Fig. 7.1 “Sextant Resection positioning”**

A single sextant angle may be used in conjunction with a fixed range LOP, as shown in Figure 7.2 (Hopper dredge positioning). In the past this was a common technique for locating hopper dredges.

On stable offshore vessels and other platforms, multiple sextant angles can be observed to several targets (*Redundant sextant resectioning*). The resultant fix can be adjusted by onboard software using least squares adjustment techniques with results being quite accurate (less than  $\pm 1$  m in some isolated cases).



**Fig. 7.2 “Hopper dredge positioning”**

### Accuracy and Quality Control

The two observed sextant angles form the loci of circles, the intersection of which is the vessel's position. Each angle forms a circle defined by three points: the two shore control points/targets and the vessel. The geometry of these two intersecting circles is a primary factor in determining the strength of a sextant resection, as the two intersecting circles converge on each other, the resultant position weakens drastically. In the best conditions, dynamic positional accuracies were rarely better than  $\pm 5$  m (95% RMS), average accuracies were generally in the 10 to 20 meter range.

The simplest method for estimating *resection accuracy* at any point is to move each angle by its estimated accuracy and assess the resultant change in position. This is readily done when automated resection computing software is available, or by noting the position shift in a station-pointer. Positional accuracy should be assessed at various points in the work area. In performing sextant resection positioning the following QC factors must be considered:

- a. sextant angles precision;
- b. observer synchronization;
- c. vessel velocity and motion;
- d. observer experience and fatigue;
- e. type of targets.

Due to design and handling, internal sextant instrument calibration is not particularly stable; therefore observers should continuously check the calibration of their sextants. This is usually done periodically during the survey, typically at the end of each survey line.

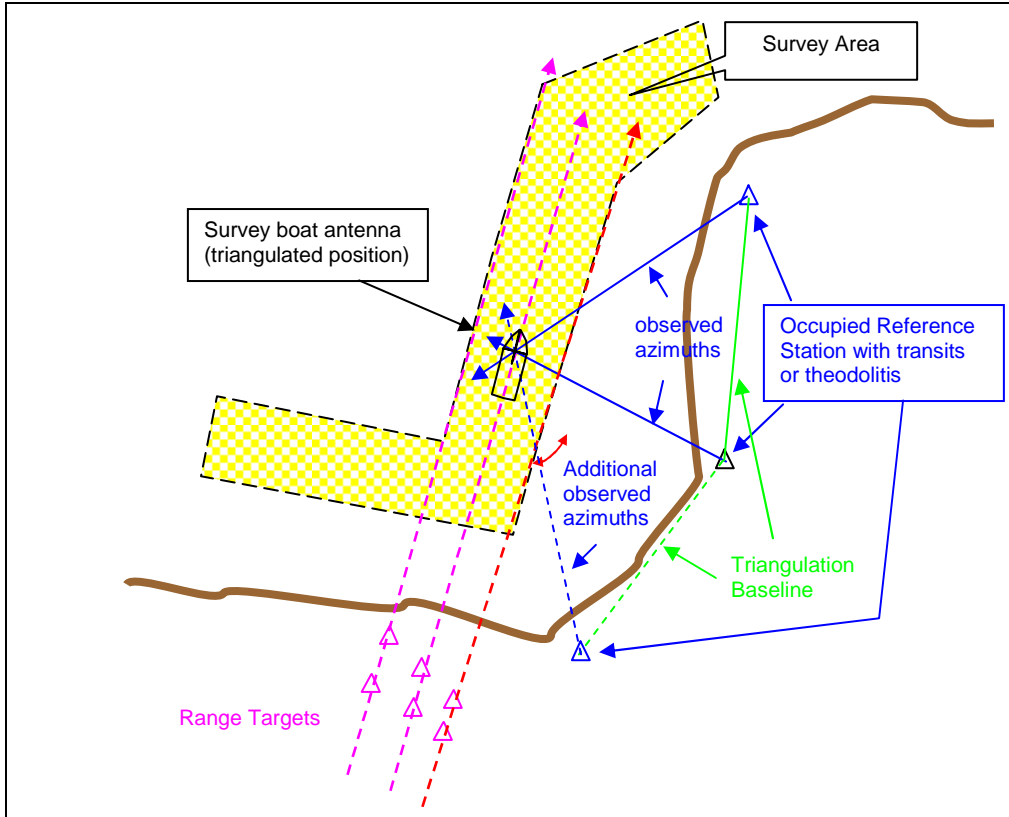
Few opportunities exist to perform quality assurance (QA) checks on sextant positioning. When more than three targets were visible, different resection positions could be compared from an anchored position.

Sextant fixes at distances approaching the limit of visibility of the marks are likely to be weak because the angles or rates of change are small. The sextant must be in perfect adjustment, and the angles measured and read with extreme accuracy, to the nearest 30 seconds of arc if necessary. If the sum of the two angles frequently approaches  $180^\circ$  with one angle often being very large and the other very small, the rate of change of angle will be rapid when the vessel is moving; thus, particular care must be taken to ensure simultaneous observations; the effects of errors introduced by failure to observe angles simultaneously is minimized when the distance of the marks from the observe are small.

#### **4.1.6.2 Triangulation/Intersection Positioning**

##### **General Description**

An offshore vessel or platform can be positioned (triangulated) by transit or theodolite angles observed from base line points on shore. This technique may have an application in areas where electronic positioning systems cannot be deployed or where increased positional accuracy is required. As indicated in Figure 7.3, two (or more) shore-based transit or theodolite observers are required. Due to the higher precision and stability of the instruments, the resultant positional accuracy can be quite good. Theodolite stations should meet the accuracy requirements for special order or order 1 surveys. The angle of intersection at the vessel should be such that a directional error of 1 minute from a theodolite station will not cause the position of the vessel to be in error by more than 1 mm at the scale of the survey; angles greater than  $30^\circ$  and less than  $150^\circ$  will usually ensure meeting this condition. Triangulation techniques are often used to supplement electronic distance measurement (EDM) or DGPS positioning of fixed offshore structures (piers, bridges, rigs, etc.) both during construction and subsequent deformation monitoring.



**Fig. 7.3 “Triangulation/Intersection positioning”**

### Accuracy

Triangulation/Intersection positional accuracy depends on the tracking accuracy of the system in use; it is related to the geometric strength of the intersection from two angles or azimuth directions and varies throughout the survey area because the angular standard errors for each instrument vary as a function of distance between the instrument and the survey vessel. The average of the standard errors of each angular measurement at the offshore vessel position, together with the computed range from each observing reference point, gives an estimate of the triangulated/intersected positional accuracy.

Multiple azimuth intersection techniques, allowing three or more additional angular observations, enables increased accuracy with redundancy provided by the additional measurements from other shore stations.

Often azimuth alignments are combined with simultaneously EDM or GPS range measurements and a least squares adjustment technique is performed, if automated acquisition is running during the survey operations

### Quality Control and Quality Assurance

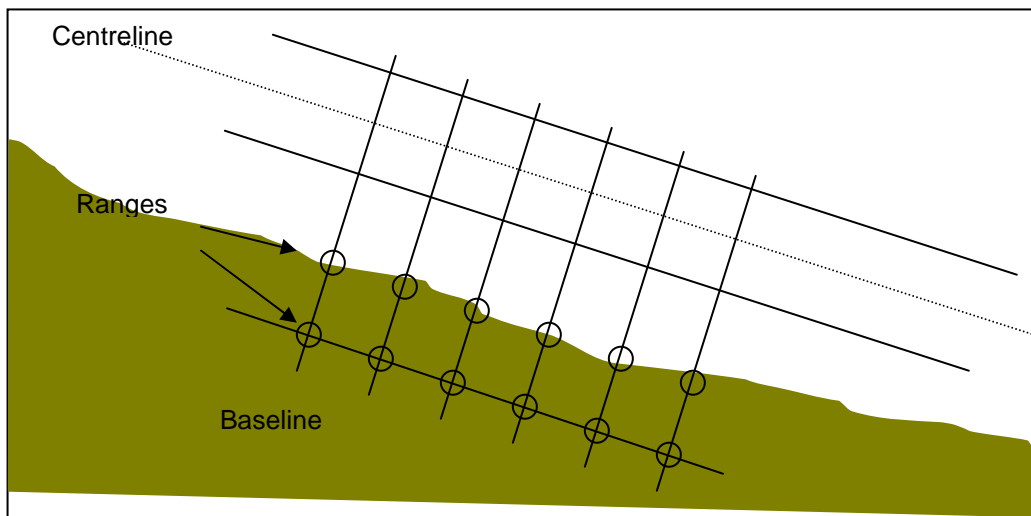
QC is performed with periodic backsight checks during the course of the survey. Independent QA should be performed with a third instrument, which is not very easy to perform in practice and normally an EDM or GPS system is used to make checks.

### 4.1.6.3 Visual Positioning

#### General Description

This traditional method was often used to locate a hopper dredge relative to known shore features or flags and is still used for a few applications, such as horizontal and vertical alignment of construction equipment, rigs, barges, etc.

Relative visual positioning techniques is now rarely performed, given the availability of microwave EPS, range-azimuth and GPS positioning methods; it is generally suitable only for non-navigation reconnaissance work where identifiable features (navigational aids, beacons, day markers, bridges and other structures or map features) on the supplied drawings, navigation charts or maps are assumed to be accurate for this standard of survey.



**Fig. 7.4 “Range poles, flags, and/or lasers set ashore for relative positioning”**

The main points of this method are:

- a. the boat maintains constant survey speed between all the identifiable objects or range intersections;
- b. fixes are taken when the survey boat is passing abeam or lateral to an identifiable object;
- c. positions are interpolated between fixes;
- d. vessel speed is assumed to be constant between fixes, which are assumed to be free of errors;
- e. position determination may be obtained by intersection of shore points and ranges established by sighting across such features;
- f. results should be used with caution due to the approximate nature of data and the marginal accuracy of such a survey.

#### Accuracy and Quality Control

Accuracy is difficult to estimate and QC is rarely performed, when using visual positioning techniques.

#### 4.1.6.4 Tag Line Positioning

##### General Description

This traditional method was often used before the 1970s to monitor dredging progress of navigation projects and traditional channel cross-section surveys and in subsurface investigation for channel obstructions and channel clearance sweep surveys. Tag Line techniques were replaced by microwave EPS and range-azimuth techniques and now have been superseded by GPS positioning methods.

Within limited distances off the baseline and with proper execution, a tag line controlled survey is an accurate and stable method of performing hydrographic surveys and other investigative work for marine design and construction:

- a. a calibrated wire rope is employed, stretched perpendicular from berths or hubs on a baseline to the survey boat;
- b. is maintained around berthing areas for critical site investigation work; where GPS signals are blocked for such surveys (however an electronic total station is preferred);
- c. usually requires no electronics or communication devices.

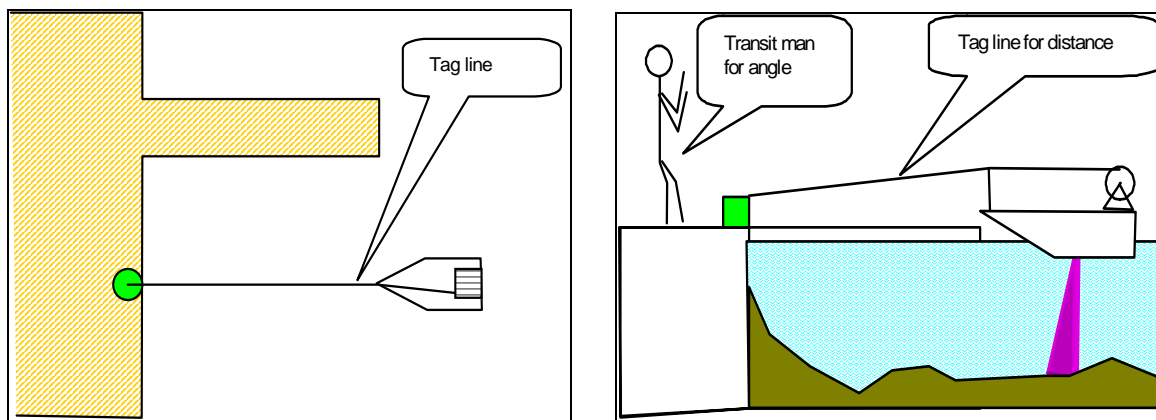


Fig. 7.5 “Tag line surveys”

##### Techniques

A tag line survey is simply a method of running cross sections from a fixed baseline.

Different survey techniques should be performed, depending on type of operations and instruments adopted as:

- a. static observations – tag line length observations are made when the boat is properly aligned on the section and the wire is pulled taut to minimise sag;
- b. dynamic or continuous tag line surveys – some tag line surveys are conducted in a dynamic mode using analogue echo sounders;
- c. baseline boat tag line extension methods – tag lines may be anchored to a floating vessel (baseline boat) that has previously been positioned by tag line or other means;
- d. constant range methods – a tag line may be used to maintain a constant range from the baseline hub;

- e. baseline layout for tag line survey – intermediate points or baseline for controlling tag line work are set using standard construction survey techniques and standards;
- f. tag line alignment methods – visual range flags, right angle prisms, transits, theodolites, sextants, and total stations are used for maintaining lateral alignment control of the survey boat, which can be the weakest part in the performance of tag line surveys, especially if strong currents are present;
- g. data recording procedures – tag line survey and related depth measurements may be recorded on worksheets or in a standard field survey book, survey data are plotted in either site plan or section formats;
- h. survey boats – any type of survey boat, equipped with tag line man-hold or powered winches, may be used to conduct tag line surveys. Generally boats' length range from 5 to 8 metres and drafts are less than 0.40 metres are essential to work in shallow water areas and to provide ease of beaching.

### **Accuracy and Calibration Requirements**

Accuracy: the positional accuracy of a point positioned by tag line may be computed using the estimated accuracy of the alignment and distance measurements; similar to that done with range-azimuth survey methods.

Calibration: flagged tag line intervals must be periodically calibrated every 3 to 6 months or after breaks against a chained measure or EDM system.

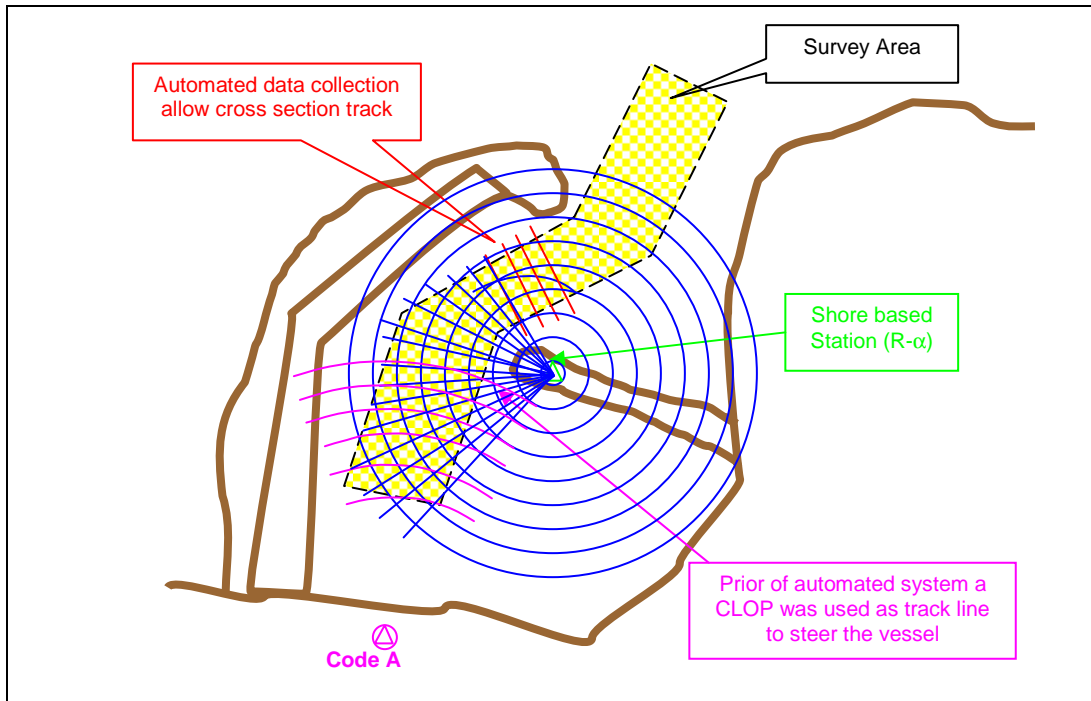
#### **4.1.6.5 Range-Azimuth Positioning**

##### **General Description**

This, once widely used positioning technique, is based on the intersection of azimuth-range measurements, generally performed from the same shore reference station, similar to a forward traverse computation, see Figure 7.6. Now days it is employed only where GPS positioning cannot be obtained due to satellite masking. The main features are:

- a. angle observations (azimuth) can be measured by transits, theodolites, or total stations;
- b. distance observations (range) can be measured by EPS devices (laser or infrared EDM, microwave EPS or total stations);
- c. data can be manually observed, noted on field book and voice-relayed to the boat by radio or digitally recorded and transmitted by radio-modem to the boat;
- d. typically used within 5 km of coastline and/or reference station;
- e. high relative accuracy is achievable depending on the equipment used (best accuracies are achieved by automated theodolites/EDM or total stations);
- f. periodic calibration or a third LOP measurement (angle or range) is essential for redundancy;
- g. a small team is required to perform the survey (relatively efficient);
- h. boats 5 to 8 metres long often is used;





**Fig. 7.6 “Range-Azimuth positioning”**

- i. theodolite with laser or infrared EDM and total station are highly accurate as range-azimuth systems for Special Order survey areas within 2 km of the reference point;
- j. microwave based EPS will rarely meet positional accuracy standards for Order 1 (2 m or 5 m);
- k. dynamic alidade or transit stadia distances meet positional accuracy standards for Order 1 (accurate to 5 meters) within ranges of only 30-50 metres, depending on conditions.

### Quality Control Procedures and Requirements

Angular orientation:

- a. the lower plate of the tracking device must initially be referenced, relative to the survey project, to the grid azimuth of the reference back sight ( $000^\circ$  line of sight);
- b. additional reference lines of sight (landmarks) should be taken as a redundant reference orientation;
- c. all reference orientation points should be selected as the farthest and most reliable visible controls, sighted on and relative errors resolved onsite;
- d. all orientation measures and grid azimuth computation must be recorded on a field book.

Periodic orientation checks:

- a. periodic orientation checks on the initial reference back sight ( $000^\circ$  line of sight) should be performed during the survey (normally every 20/30 fixes or 5/10 minutes or at the end of each survey line) to ensure that no horizontal or vertical misalignment occurred to the instrument;

- b. additional reference lines of sight (landmarks) should be taken, this should normally be completed at the beginning and at the end of the survey session;
- c. periodic readjustment and re-levelling of the instrument should be performed as required after these checks;
- d. all periodic checks and re-levelling operations should be noted into the field book;
- e. if the orientation check indicates a significant misalignment, all fixes taken since the previous orientation check must be rejected and the measurements rerun.

Quality assurance checks:

- a. independent positional checks are rarely available as with most visual survey positioning methods;
- b. carrier phase RTK-DGPS techniques allow independent positional checks, but these will be performed with geodetic receivers in static mode and in the topographic range field;
- c. for critical navigation surveys, position checks should always be done with the vessel as near as possible to a reference control point.

#### **4.1.6.6 Electronic Positioning**

##### **General Description**

A variety of systems have been developed, most of which have become obsolete since GPS became fully operational. However, the basic operating concepts behind land-based Electronic Positioning Systems (EPS) and related trilateration positioning (including GPS) have not significantly changed.

Land-based (or terrestrial) positioning systems use time difference and trilateration techniques to determine a position.

##### **Electronic Positioning Systems (EPS)**

In general EPS are classified according to their operating frequencies or the bandwidth, see Table 7.2 of Appendix 3 to Chapter 7, which determine the operating range and accuracy, and thus a system's applicability for a particular type of work. In general, the higher the frequency of the system and the shorter the wavelength, the greater the achievable accuracy possible in the resolved position, see Table 7.2 of Appendix 3 to Chapter 7.

Medium-frequency Electronic Positioning Systems (RAYDIST/DECCA):

- a. systems were first developed in 1950s but they are no longer used;
- b. systems operated by time/phase differencing methods, resulting in either circular or hyperbolic lattices (time differences);
- c. systems required repeated calibration to resolve whole-wavelength (lane) ambiguities and continual monitoring during the course of the survey to resolve lane or cycle slips, similar to the integer ambiguity determination requirements for modern day DGPS;
- d. onsite calibration was essential to maintain accuracy, but in very far offshore surveys calibration was often impossible;
- e. visual positioning techniques were used to calibrate these systems.

Low-frequency Electronic Positioning Systems (LORAN-C):

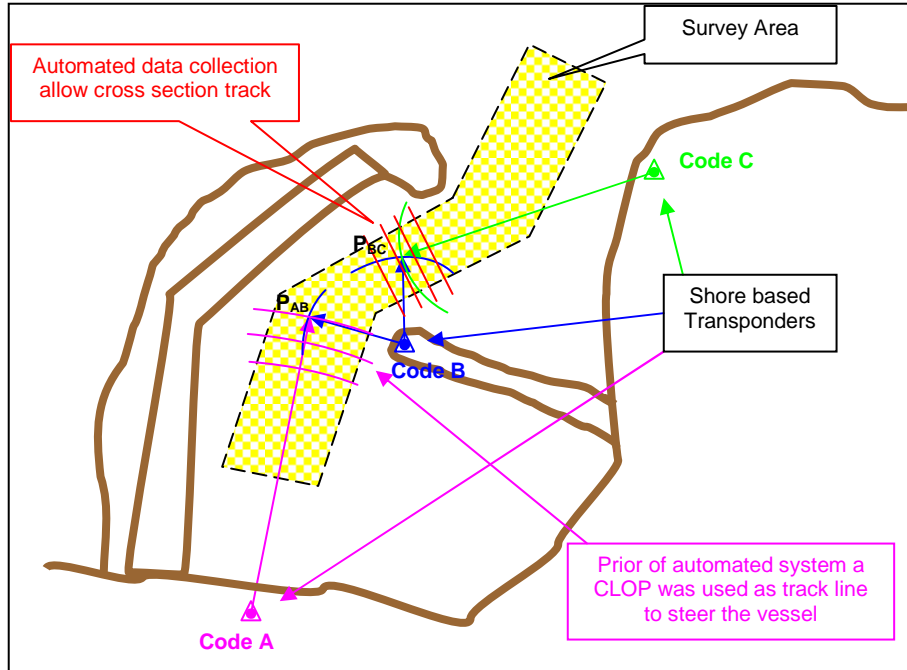
- a. the primary marine and airborne navigation system for over 40 years;
- b. a low-frequency time-differencing hyperbolic system;

- c. suitable only for general navigation or reconnaissance surveys (Order 3 when calibrated);
- d. daily near-site or onsite calibration is critical if any semblance of absolute accuracy is to be maintained;
- e. absolute positional accuracy is about + 450 metres (+ 0.25 mile) at best, without onsite calibration.

### **Range-Range EPS**

These microwave EPS (hyperbolic or circular) were introduced in the 1970s and remained the primary positioning system up until the mid 1990s, thereafter their use declined when differential GPS techniques became available for large areas. Nowadays microwave EPS (Range/Range) are still in use in those areas where poor GPS signal coverage occurs.

- a. Trilateration is the process performed by the Range/Range microwave EPS when determining the co-ordinates by intersection of measured distances from two (or more) shore control points:
  - i. a Circular Line of Position (CLOP) is associated with the distance from each shore station;
  - ii. each pair of CLOP generates two intersection points, which are generated each side of the connecting baseline between the two shore stations points;
  - iii. each EPS uses its own method to solve this ambiguity, by orientation to initial reference point co-ordinates or by referencing the calculated position relative to the azimuth of the baseline;
  - iv. initially EPS distances were visually observed and steered, performing manual data logging in a workbook or field book with manual fixing on a plotting sheet;
  - v. modern EPS use built-in automated data acquisition systems that log the ranges and compute the relative positions, subsequently sending this data to a helmsman display unit and a track plotter;
  - vi. present-day EPS, and also GPS systems, transmit the raw digital data to a PC running a suitable Acquisition and Control Process package, capable of synchronizing position and sounding in logged data files, whilst performing real-time positioning QC and tracking the position in several windows selected on the main operator and helmsman monitors.



**Fig. 7.7 “Two Range Intersection”**

- b. Constant range tracking provides a good backup capability should failure occurred in the automated positioning and guidance system. When no automated techniques are available, the vessel follows a CLOP:
- i. by keeping a constant range from one reference station;
  - ii. by fixing at range intercepts from the other reference station;
  - iii. by proceeding at low speed, to produce a better accuracy in positioning and ease the helmsman’s task of following the curve range pattern;
  - iv. survey lines are circular, not aligned to the project co-ordinate system and often not orthogonal to the main bathymetry.
- c. Automated range-range tracking:
- i. the range intersection co-ordinates are automatically computed from the precise co-ordinates of the shore stations;
  - ii. the point co-ordinates are transformed relative to the project alignment co-ordinate system (station-offset);
  - iii. analogue/digital course indicators or left-right track indicators receive positional data, allowing the tracking of any cross section or offset range;
  - iv. position fixes are taken manually by the observer from a receiver or track plotter, recording co-ordinates on in suitable workbook;
  - v. at each fix, the depth is marked on the paper trace of the analogue echo-sounder and the value noted in the workbook;

- vi. the correlation between position and sounding will be performed during the post-processing stage;
- vii. digitised depth data are correlated in real time with positional data in a data acquisition software system at regular preset intervals.

### **Range-Range Accuracy**

The intersection accuracy is a function of two factors:

- a. The range accuracy of distances (or standard deviation  $\sigma$ );
- b. The angle of intersection that varies relative to the baseline, positional accuracy varies as the vessel changes its position in the survey area.

### **Quality Control**

Main quality control criteria to be considered on Microwave EPS accuracy:

- a.  $\alpha$  angle of intersection has major effect on position determination and should be between  $45^\circ$  and  $135^\circ$ ;
- b.  $\sigma$  isn't constant with distance from a shore station and in general is in the order of  $\pm 3$  m rather than the  $\pm 1$  m or 2 m stated by manufacturers for ideal or well calibrated conditions;
- c. the average positional accuracy ( $\sigma \pm 3$  m) can vary from 5 to 10 metres.

### **Multiple Range Positioning**

Multiple range positioning techniques. (ie. Racal Micro Fix, Sercel Syledis, Motorola Falcon VI)

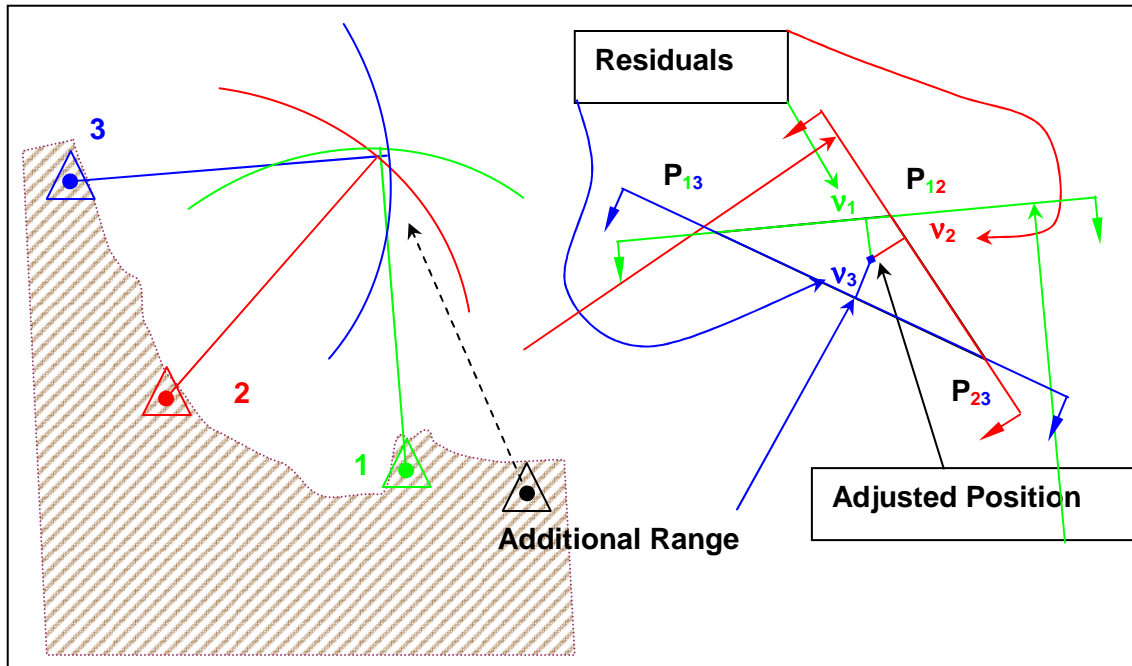
The position is determined from the computed co-ordinates of the intersections of three or more simultaneously observed range circles.

The CLOPs don't intersect at the same point because each range contains observational errors:

- a. three different co-ordinates result from three observed ranges and six separate co-ordinates result from four observed ranges;
- b. an adjustment of these co-ordinates gives the final position and is normally performed on-line at each update cycle generally by a least-squares minimisation technique or simply by the strongest angle of intersection or not weighted average of all the intersecting coordinates.

The positional data are then transformed to a project-specific co-ordinate system as described for a two-range system:

- a. the use of multiple ranging minimises uncertainties with the vessel position being obtained by adjustment of these ranges to a best fit; an on-line accuracy assessment is accomplished by evaluating the positional intersection misclosure of CLOPs which contain errors ( see Figure 7.8);



**Fig. 7.8 “ Multiple CLOPs Intersection”**

- b. an assessment of the range measurement accuracy may be obtained by computing the residual range errors ( $v$ ) for each position (automated software, using a least-squares type of adjustment, can provide an accuracy estimate of the positional RMS error at each position update);
- c. automated EPS give an alarm when RMS exceed prescribed limits, assuming a constant initial standard error within the survey area.

### Calibrations and Quality Control

The process of calibrating a microwave EPS is performed by the following basic steps:

- a. independent determination of the vessel's antenna location;
  - b. comparison of differences between the observed microwave distances and the distances computed from an independent measuring system (if observing the direct distances);
- or**
- b. comparison of differences between the observed microwave co-ordinates and those computed from the independent system;
  - c. performing a series of independent calibrations (*Repeated Calibrations*), the correction to the EPS, to be applied at the console or stored into position computation software, is represented by the mean range difference.

The systems and methods used to perform an independent calibration would include:

- a. EDM calibration – series of EDM distance readings is directly compared with the simultaneously observed microwave ranges and corrections are then applied;

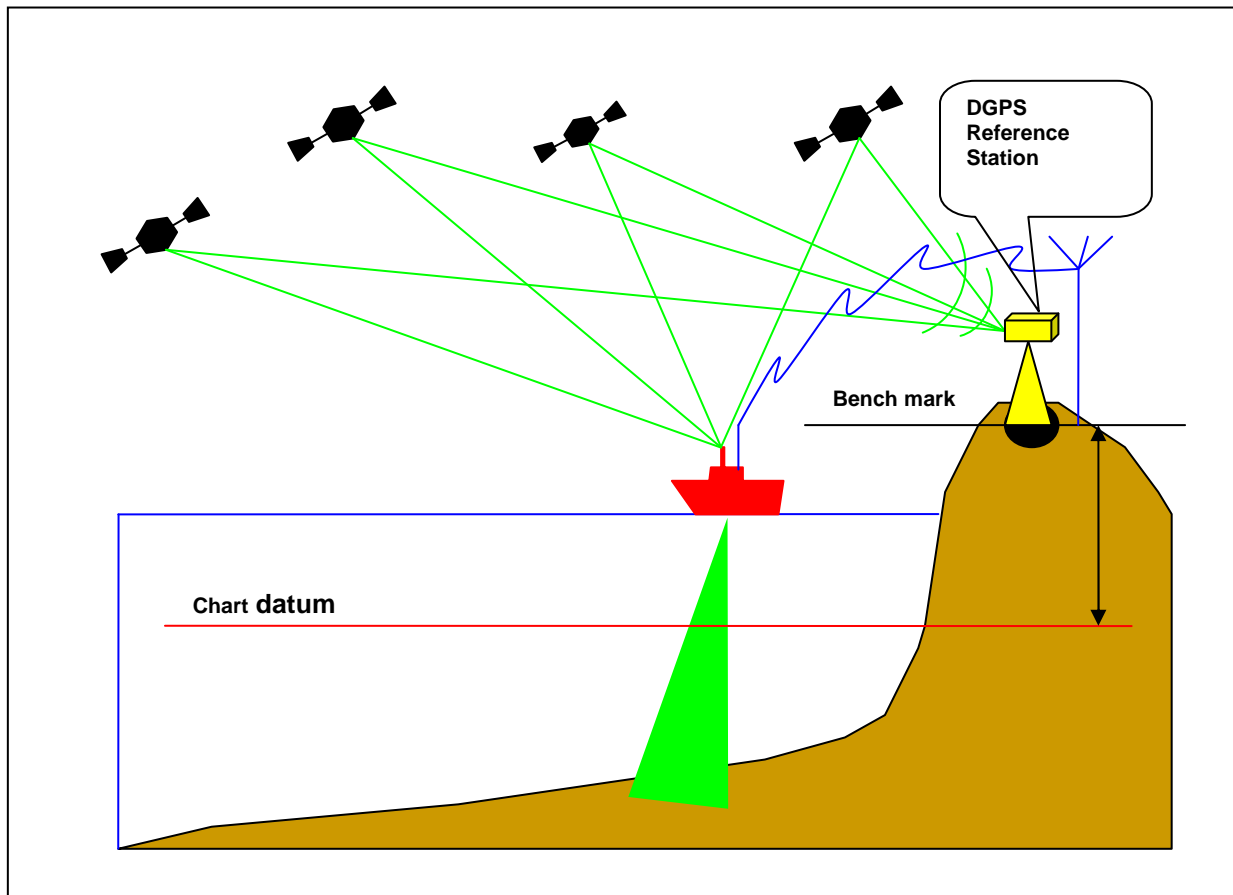
- b. baseline calibrations – the simplest microwave EPS calibration method, the survey vessel is positioned at a point on the baseline between two shore stations and the computed distance is compared with the combined observed ranges from the microwave system, range corrections are computed and applied. This method should be repeated at various points on the baseline and should be performed between all pairs of shore stations;
- c. total station instrument calibration – the observed co-ordinates of an automated positioning system can be directly compared with the more accurate co-ordinates obtained from total station EDM measurements;
- d. triangulation intersection – the most accurate method of microwave calibration is performed in a dynamic environment. Three theodolites are used for this high-accuracy triangulation calibration, a series of 5 to 10 measurements, intersection fixes, to the moving survey vessel. For each series of measurements, the triangulated positions are computed, inversed, and converted to grid distances which are compared against the simultaneously observed microwave ranges. An estimate of the statistic validity of the mean range difference must be calculated as previously explained;
- e. sextant resection – this method is valid only when resection geometry is ideal, near the shore line and a very slow vessel motion. A numbers of simultaneous resection angles (5 to 10) and corresponding microwave EPS distances are observed with three sextants centred near the EPS antenna to minimise eccentric errors. Resection computation should performed using suitable software providing a quality indication of the resection based on the geometry and estimated standard error of the observed angles, to judge whether applying a mean correction to the range is statistically appropriate.
- f. General QC criteria for EPS:
  - i. the static calibration does not simulate the dynamic survey condition;
  - ii. the calibration must be performed within or close as possible to the survey area, to simulate the real conditions within the project area;
  - iii. the accuracy of the independent calibration procedure followed must be better or at least equal to the calibrating microwave EPS;
  - iv. the multi-path residual effects can be reduced but not eliminated by calibration procedures due to survey vessel antenna location and orientation;
  - v. calibrations of pulsing microwave EPS are valid only for the particular range measurement system used;
  - vi. the more accurate measurement systems used to calibrate EPS must also be independently checked, or verified, to prevent blunders (GPS, Total station, theodolites, etc);
  - vii. calibration procedures must be consistent during the course of a project.

Some of these basic criteria, described for performing EPS calibrations, are also applicable to GPS positioning techniques.

#### 4.1.6.7 Global Positioning System (GPS)

##### General Description

During the 1990s the Global Positioning System (GPS) has become the worldwide standard positioning and navigation system and has replaced almost all other techniques. Poor GPS satellite coverage only occurs in isolated instances over relatively small areas, in these cases the traditional terrestrial methods will need to be employed. Differential GPS systems allow for world wide coverage, they do not always require the site selection/deployment effort required for terrestrial systems however careful pre-survey calibration and post survey validations are still required; accuracies now exceed those of any other hydrographic survey positioning system.



**Fig. 7.9 “Differential GPS positioning of a hydrographic survey vessel”**

The system consists of two absolute positioning services, the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS):

- a. SPS is available to civilian users, using the C/A-code on the L1 carrier, it provides absolute accuracies of 10-30 meters in absolute positioning mode;



- b. PPS was developed for the U.S. military and other authorized users; it uses the P(Y)-code on the L1 and L2 carriers providing an absolute accuracy of 5-15 meters in absolute positioning mode.

For many applications, this absolute positioning does not provide sufficient accuracy. Differential GPS (DGPS) is a technique which can provide relative positioning with an accuracy of a few meters using code phase measurements to a few millimetres with carrier phase measurements. DGPS requires two or more GPS receivers to be recording measurements simultaneously and processing software to reduce or eliminate “common errors”. With a reference system positioned at a known survey control point, DGPS data can be used to determine baselines between stations and establish the positions of other receivers within the same reference system. Code and carrier phase DGPS, when operating in a differential mode, can be tracked in real-time for the positioning of moving platforms, dredges, survey boat and vessels (see Figure 7.9) to provide real-time information at accuracies required for hydrographic surveying and/or dredge positioning.

### **Tracking Techniques** (see paragraph 6.1.4.1 of Chapter 2)

Phase tracking techniques are:

- a. carrier phase tracking;
- b. code phase tracking.

### **Accuracies**

The absolute range measurement accuracies or standard deviation achievable with GPS depends on:

- a. the type of code used (C/A or P);
- b. a three-dimensional (3-D) confidence ellipsoid describing the uncertainties in all three geocentric co-ordinates, when coupled with the GDOP of the satellites during the position determination;
- c. the time and the location of the changing satellite geometry.

The nominal accuracy statistics for a GPS user are defined by error propagation techniques. The user range measurement accuracies refer to geocentric co-ordinates, which can be transformed to a local datum, and to a 3-D covariance matrix, which defines and assess the dimensions (direction or co-ordinate) of the error ellipsoid in the reference system.

The more usual methods to describe error measures are listed below:

- a. 2-D (horizontal) GPS positional accuracies are normally estimated using a Root Mean Square (RMS) radial error statistic;
- b. 3-D GPS accuracy measurements are most commonly expressed by Spherical Error Probable, or *SEP*. This measure represents the radius of a sphere with a 50% confidence or probability level and the spheroid radial measure only approximates the actual 3-D ellipsoid, representing the uncertainties in the geocentric co-ordinate system.
- c. for 2-D horizontal positioning, *CEP* (Circular Error Probable) is commonly used as the probable or statistic error measure, represented the radius of a circle containing a 50% probability of position confidence;

## Accuracy Comparisons

It is important that GPS accuracy measures clearly identify the statistics from which they are derived. A “20 meter” or “5 meter” accuracy statistic is meaningless unless it is identified as being 1-D, 2-D, or 3-D, together with an applicable probability level. In addition, absolute GPS point positioning accuracies are defined relative to an earth-centred co-ordinate system/datum. This co-ordinate system will differ significantly from local project or construction datum. Nominal GPS accuracies may also be published as design or tolerance limits, and actual accuracies achieved can differ significantly from these values.

## Relative Accuracy Measures

Hydrographic surveys performed according to IHO/S-44 Standards are concerned with absolute world-wide ( $\varphi$ ,  $\lambda$ ,  $h$ ) positional accuracy at 95% confidence level, but normally engineering, construction, and dredging surveys are concerned with local project coordinates ( $X$ ,  $Y$ ,  $h$ ), and with ensuring high accuracy within a local construction project. The relative accuracy measure is expressed typically in parts per million (ppm) as a function of the distance between two points or receivers and usually given at the one-sigma standard error (or 68% standard deviation) level.

## Dilution of Precision (DOP)

GPS errors resulting from satellite configuration geometry can be expressed in terms of Dilution of Precision (DOP), which is the geometric strength of the configuration of satellites observed during the survey session. In mathematical terms, DOP is a scalar quantity used in an expression of a ratio of the positioning accuracy (or of the standard deviation of one co-ordinate to the measurement accuracy). DOP represents the geometrical contribution of a certain scalar factor to the uncertainty (i.e., standard deviation) of a GPS measurement. In 2-D (horizontal) positioning it refers to the HDOP factor.

## Reference Datum

In general differential survey methods are concerned with relative co-ordinate differences, but in absolute positioning and for navigation purposes we must consider variations within a global reference system used by the NAVSTAR GPS. Thus, GPS co-ordinate differences or transformations from the World Geodetic System 84 (WGS 84) reference system must be applied to any type of local reference datum. On the North American continent the co-ordinates of WGS 84 are highly consistent with North American Datum 83 (NAD 83). The European Terrestrial Reference Frame (ETRF89) is a realisation of WGS 84 for the European Continent. Each nation in Europe has determined their own transformation to tie the ETRF to the local datum.

## Error Sources (see paragraph 6.1.3 of Chapter 2) and Calibration Requirements

The accuracy of GPS is a function of errors and interferences on the GPS signal and the processing technique used to reduce and remove these errors. Similar to range-range microwave systems, GPS signals are highly affected by humidity and multi-path; additional errors are caused by the 20,000 km path through the ionosphere and troposphere layers. It should be remembered that satellite signals can be altered for US national security reasons by the use of Anti Spoofing (AS). Differential techniques close to a reference station can eliminate most of these errors, however the further the remote operates from the reference station, the less similar will be the errors received by both receivers.

DGPS operation has no prescribed calibration requirements (check list), unlike microwave or R/A systems; the major blunders to check for are:

- a. incorrect project datum or geodetic reference datum;

- b. incorrect master station co-ordinate values;
- c. incorrect measurement of antenna height values;
- d. DGPS mode not selected in the unit;
- e. RTCM-104 input/output format not selected.

### Positioning Methods

Two general operating methods, used to obtain GPS positions for dynamic horizontal control, have a variety of applications for hydrographic surveys at sea:

- a. absolute point positioning;
- b. relative positioning (DGPS).

In general, absolute point positioning involves only a single passive receiver and is not sufficiently accurate for precise surveying or hydrographic positioning requirements. It is, however, the most widely used military (PPS) and commercial (SPS) GPS positioning method. Relative (Differential) positioning requires at least two receivers and can provide the accuracies required for basic land surveying and offshore positioning.

#### Absolute Point Positioning (Pseudo-Ranging)

The GPS receiver generates a navigation solution by pseudo-ranging, measuring an approximate distance (pseudo-range) between the antenna and the satellite by correlation of a satellite-transmitted code and a reference code created by the receiver, no corrections are made for errors in synchronization between the clocks in the transmitter and the receiver. The distance which the signal has travelled is equal to the velocity of the transmission from the satellite multiplied by the elapsed time of transmission. Additional delays (errors), which can affect positional accuracy, are caused by tropospheric and ionospheric conditions. To create a GPS 3-D position, at least, four pseudo-range observations are required to resolve the constant clock biases ( $t$ ) contained in both the satellite and the ground-based receiver.

The solution of four pseudo-range observation equations, containing four unknowns ( $X$ ,  $Y$ ,  $Z$  and  $t$ ), gives the solution for the 3-D position of a point (for a 2-D location only three pseudo-range observations are needed), it is highly dependent on the following accuracies:

- a. the accuracy of the known co-ordinates of each satellite (i.e.,  $X_s$ ,  $Y_s$ , and  $Z_s$ );
- b. the accuracy of the modelled atmospheric delays ( $d$ );
- c. the accuracy of the resolution of the actual time measurement process performed in a GPS receiver (clock synchronization, signal processing, signal noise, etc.);
- d. the accuracy of an absolute point position is a function of the range measurement accuracy and the geometry of the satellites (DOP).

Dilution of Precision (DOP) is a description of the geometrical contribution to uncertainty in a GPS determined point position and is roughly related to the physical orientation of the satellites relative to the ground receiver along with the range measurement accuracy.

Static Solution - as with any measurement process, repeated and redundant range observations to the satellites at varying orientations will enhance the overall positional accuracy and reliability. In static mode with a stationary GPS antenna, range measurements to each satellite may be continuously measured over the varying orbits of the satellite(s). The altering satellite orbits create changing positional intersection geometry over the same ground position. In addition, simultaneous range observations to

numerous satellites can be adjusted using weighting techniques based on the strength of intersection and pseudo-range measurement reliability.

Dynamic Solution - In dynamic mode where the GPS antenna is moving, range measurements to each satellite are unique due to the altering orbital locations of the satellite(s). The varying satellite orbits and the vessel speed cause changing positional intersection geometry over the moving GPS antenna position.

The NAVSTAR GPS satellite system gives two levels of absolute positioning accuracy:

- a. *Standard Positioning Service (SPS)*. The SPS is capable of achieving real-time 3-D absolute positional information in the order of 10-30 m (95% confidence level on horizontal accuracy). US DoD has implemented Anti-Spoofing (AS), which interchanges the P code with a classified Y code, thus denying the SPS user the higher P code accuracy;
- b. *Precise Positioning Service (PPS)*. Non-military PPS users must be authorized by the US DoD to have a decryption device capable of deciphering the encrypted GPS signals. This authorization must be obtained from the National Security Agency (NSA). USACE is an authorized user; however, actual use of the equipment has security implications. PPS users can obtain real-time absolute 3-D positional accuracy in the order of 16 m SEP (or 5-15 m at 95% confidence level on horizontal accuracy).

The US DoD security action does not significantly impact a hydrographic user operating in a differential positioning mode.

Absolute positioning (SPS/PPS) only provides real-time absolute positional accuracies and will not satisfy the IHO/S-44 hydrographic surveying requirements for Special Order and Order 1. It does have general navigation applications and will eventually replace LORAN-C and other navigation systems for ships and aircraft.

### **Differential Point Positioning (DGPS)**

Differential positioning is the technique used to position one point relative to another, both receiving stations simultaneously observing the same satellites. Since errors in the satellite position ( $X_s$ ,  $Y_s$ , and  $Z_s$ ) and atmospheric delay estimates ( $d$ ) are effectively the same, they can be ignored to a large extent. This method can be performed by using code or carrier phase measurements and can provide results in real-time or post processed.

- a. *DGPS Code Phase tracking*. The technique consists of two GPS receivers; one set up over a known point and one moving from point to point or placed on a moving survey vessel, measuring pseudo-ranges to at least four common satellites. Since the positions of the satellites are known and one of the receivers is over a fixed known point, a “known distance” can be computed for each observed satellite. This “known distance” can then be compared against the “measured distance” (or Pseudo Range) to obtain a Pseudo Range Correction (PRC), which is computed for each satellite being tracked at the fixed point. Each PRC can then be applied to the moving or remote receiver to correct the measured distances. Code phase tracking has primary applications to real-time positioning systems with meter-level accuracies. It is sufficient for hydrographic survey positioning which meets IHO S-44 requirements for Order 1 surveys, since meter-level positioning suffices for the vast majority of these purposes.

- b. *DGPS Carrier Phase tracking.* This is the most accurate GPS survey technique and the relative positional accuracies are of the order of two to five parts per million (ppm) between two GPS receivers (one at a known reference point and the other at an unknown location or aboard a moving platform). The tracking method uses a similar formulation of pseudo-ranges used in code phase tracking systems described above, but with a more complex process when the carrier signals are tracked. The short wavelength (19 cm) necessitates the adding of an ambiguity factor to the solution equations to account for the unknown number of whole carrier cycles over the pseudo-range. Carrier phase tracking provides for a more accurate range resolution due to the short (19 cm) wavelength and the ability of a receiver to resolve the carrier phase down to about 2 mm. This method is referred to as real-time kinematic or RTK and provides 3D positions accurate to a few centimetres over ranges up to approximately 20 kilometres. It is applicable to hydrographic survey positioning and meets IHO/S-44 requirements for Special Order surveys and may be employed with either static or kinematic receivers.
- c. *Advantage* of the code phase (DGPS) over the carrier phase(RTK):
  - i. wavelengths are much longer than the carrier wavelengths, eliminating the ambiguity problem.
- d. *Disadvantage* of the code phase (DGPS) over the carrier phase(RTK):
  - i. longer wavelengths decrease the system accuracy;
  - ii. longer wavelengths are more affected by signal multipath.

### **Real-Time Dynamic DGPS Positioning System (Code Phase)**

The system in general includes:

- a. reference station equipment (master);
- b. communications links;
- c. rover station equipment (remote user).

There are several DGPS services that provide real-time pseudo-range corrections:

- a. radio beacon navigation services (Beacon IALA System);
- b. commercial satellite subscription services;
- c. commercial land base DGPS network services (telephone or mobile phone links);
- d. local DGPS systems.

Local DGPS systems are normally installed or used by the agency responsible for a survey, where other services do not provide coverage or sufficiently good accuracy to meet survey requirements.

### **Reference Station**

The reference receiver consists of a GPS receiver, antenna, and processor that:

- a. is placed at a known co-ordinated station with an unobstructed view of the sky from at least 10° above the horizon;
- b. GPS antenna should be erected clear of objects likely to cause multi-path or interference (avoid areas with antennas, microwave towers, power lines, and reflective surfaces);

- c. measures timing and ranging information broadcast by the satellites;
- d. computes and formats, every 1 to 3 seconds, the pseudo range corrections (PRC) then transmits, broadcasting via the communications link, to the operator's equipment in the offshore vessel; the recommended data format is that proposed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104 v 2.0;
- e. performs QC functions and determines the validity and quality of the computed PRCs.

### **Communications Link**

- a. the communications link is used as a transfer medium for the differential corrections, the type is dependent on the user's requirements and the minimum transmission rate should be 200 bits per second (bps);
- b. communication links operating at Very High Frequency (VHF), Ultra High Frequency (UHF) and High Frequency (HF) are viable systems for the broadcast of DGPS corrections, with ranges extending out from 20 to 50 km (VHF/UHF) and up to 200 km (HF), depending on local propagation conditions and site elevation. The disadvantages of UHF and VHF links are their range being restricted to line of sight and the effects of signal masking from islands, structures and buildings, multi-path and licensing issues;
- c. communication links require a reserved frequency of operation to avoid interference with other activities in the area, all frequencies need authorisation for use within each nations geographical area of responsibility;
- d. several companies offer subscriptions for satellite communications, telephone or mobile phone communications systems, capable of being used for the transmission of the PRCs;
- e. satellite and phone communication systems are less limited in range than UHF/VHF systems but are usually higher in price.

### **User Equipment**

Using the technology of differential pseudo-ranging, the position of a survey vessel can be calculated relative to the reference station with a receiver (the user equipment) that consists of real-time code phase tracking DGPS, antenna and processor:

- a. should be a multi-channel single frequency (L1) C/A code GPS receiver;
- b. is capable of receiving the differential corrections from the communications link in the RTCM SC-104 V.2.0 format and then applying those corrections to the measured pseudo-range;
- c. receiver update rate should be 1 to 3 seconds;
- d. output from the rover receiver should be in the NMEA-183 format as the most widely used format for input into hydrographic survey software packages;
- e. equipment should be capable of maintaining positional tolerances for surveys at speeds up to 10 knots;
- f. receivers should not bias the position during vessel turns due to excess filtering.

## Separation Distances

- a. the differential tropospheric and ionospheric corrections are not presently applied to internal solutions of most GPS receivers and these errors contribute to horizontal position errors on average 0.7 m per every 100 km;
- b. the type of data link in use will be a limiting factor on the separation distance between the reference station and mobile receiver, the reference station may need to be moved from one point to another so that the minimum separation requirements are maintained.

## Satellite Geometry

The Horizontal Dilution of Position (HDOP) is the critical geometrical component that:

- a. in Order 1 and 2 surveys HDOP <5;
- b. the 24 Block II GPS satellites constellation maintains a HDOP of approximately 2 to 3 most of the time.

## Other DGPS Services (Radiobeacon Navigation Service and Commercial WAAS)

### Radiobeacon Navigation Service

The main function of the Radiobeacon Navigation Service is to provide aids to navigation in navigable water covered by the service; the object is to substitute Loran-C and Omega systems, which were used as the primary navigation systems for offshore marine navigation, with full coverage from GPS for more accurate positioning. Many nations have commissioned real-time positioning systems for their coastal areas, rivers and lakes regions, utilising DGPS and marine radiobeacon technology; there is a desire for other maritime governments to expand the coverage to all offshore waterways and eventually have entire world coverage.

- a. System set-up and configuration:
  - i. GPS Radiobeacon:
    - N. 2 GPS L1/L2 geodetic reference station receivers with independent geodetic antennas to provide redundancy and a marine radiobeacon transmitter with transmitting antenna;
    - N. 2 combined L1 GPS/Modulation Shift Key (MSK) receivers used as integrity monitors, each one utilises an independent GPS antenna and a MSK near-field passive loop antenna.
- b. Site location:
  - i. the location of the reference stations' GPS antennas are known co-ordinated geodetic control points based on the ITRF [i.e. ETRF (European Terrestrial Reference Frame) datum for Europe and NAD 83 (North American Datum of 1983) datum for USA/Canada];
  - ii. GPS C/A-code pseudo-range corrections are computed and transmitted via a marine radiobeacon;

- iii. the system on board user vessels consists of a marine radiobeacon receiver and a GPS receiver (or an integrated GPS/Radiobeacon receiver) with the ability to accept and apply pseudo-range corrections; with accuracies of less than 5 m achievable dependent on the type and quality of the user's GPS receiver, distance from the reference station and the satellite geometry.
- c. Data transmission (data types):
  - i. the corrections and other information are transmitted using the Type message of the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) version 2.1 data format;
  - ii. more detailed descriptions of these message types are explained in the Broadcast Standard available for the Radiobeacon Navigation Service of each nation;
  - iii. corrections are generated for a maximum of nine satellites tracked by the reference station GPS receiver at a minimum elevation angle of  $7.5^\circ$  above the horizon; if more than nine satellites are observed above  $7.5^\circ$ , the corrections are based on the nine satellites with the highest elevation angles;
  - iv. satellites below  $7.5^\circ$  elevation are masked due their susceptibility to multipath and spatial decorrelation;
  - v. corrections are normally transmitted at a 100 or 200 baud rate;
  - vi. corrections can be considered valid for a period of 15 seconds from generation;
  - vii. using corrections more than 30 seconds old, particularly for positioning of a moving platform, may cause spikes.
- d. Availability and reliability of the system:
  - i. the system maintains a broadcast availability that exceeds 99.7%, in designed coverage areas, assuming a healthy and complete GPS constellation;
  - ii. signal availability, in most areas, will be higher due to the overlap of broadcast stations;
  - iii. each site is equipped with two integrity monitors (i.e. a GPS receiver with a MSK radiobeacon) that are mounted over known positions, they receive the pseudo-range corrections from that site and compute a position that is compared to the known location to determine if the corrections are within the expected tolerance;
  - iv. the corrected positions calculated by the integrity monitors are sent via phone lines to the control monitoring stations, which notify users via the type 16 message of any problems with a radiobeacon site within 10 seconds of an out-of-tolerance condition.
- e. Coverage:
  - i. an updated coverage map can be found at the Radiobeacon Navigation Service web site of each participating nation, under the DGPS section.
- f. User requirements and equipment:
  - i. to receive and apply the pseudo-range corrections generated by the reference station, the user needs to have a MSK Radiobeacon receiver with antenna and, at a minimum, a L1 C/A code GPS receiver with antenna or a combined MSK radiobeacon and GPS receiver with a combined MSK and GPS antenna, a more expensive option.



The MSK receiver demodulates the signal from the reference station and generally will automatically select the reference station with the strongest signal strength to track or it will allow the user to select a specific reference station. Since the reference station generates corrections only for satellites above a  $7.5^\circ$  elevation, satellites observed by the user's GPS receiver below a  $7.5^\circ$  elevation will not be corrected.

- g. Position QC tolerance checks and calibrations:
- i. most precise DGPS augmentation systems are capable of providing sub-meter accuracies at reasonable distances from the nearest reference station, however, at increasing distances spatial decorrelation errors (due to differing ionospheric/tropospheric conditions) can induce systematic positional biases;
  - ii. in general, under nominal atmospheric conditions, less than 5 m RMS (95%) positional accuracy may be achieved at distances upwards of 200 miles;
  - iii. to confirm positional accuracy is better than the 5 m tolerance, a static check position should be obtained by occupying a known survey point near the project area;
  - iv. when operating with the Radiobeacon Navigation Service, static positions should be observed from different radiobeacon reference stations to ascertain if positional systematic biases are present, in practice the closest beacon will normally be with minimal biases;
  - v. when large or ambiguous positional biases occur in a project area, it may be necessary to establish a local DGPS network (code or RTK carrier) for observing different beacon positions in a static comparison;
  - vi. a similar process should be performed when using Commercial DGPS Wide Area Augmentation Systems (WAAS, GLONASS, EGNOS, GALILEO, MSAS etc).

### **Real-Time Dynamic RTK DGPS (Carrier Phase)**

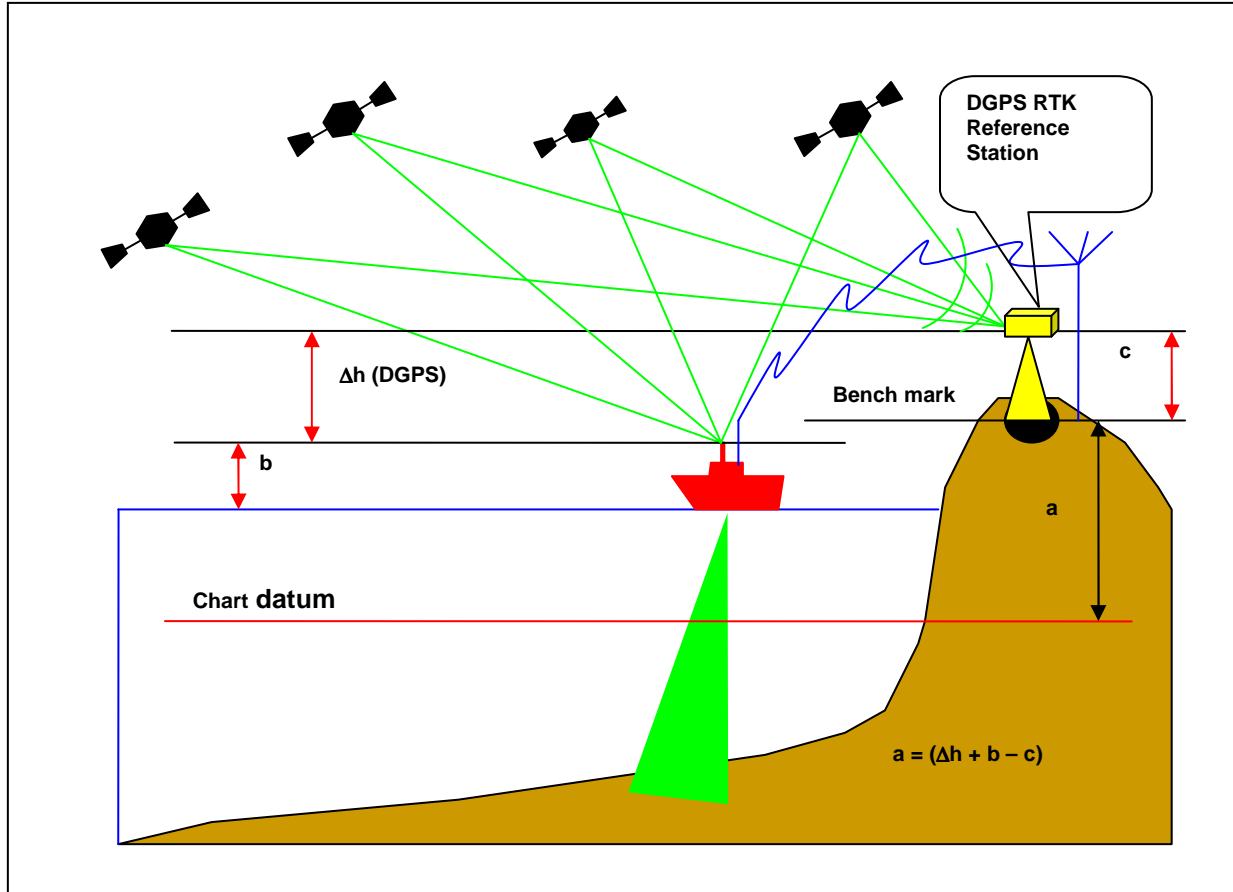
#### **General**

The DGPS carrier phase is capable of yielding decimetre accuracy on a moving vessel within the geographic area (20 km.), both horizontally and vertically. This technology, known as 'On The Fly', can provide real-time elevations of survey vessels.

Current kinematic techniques allow for the ambiguities to be resolved while the receiver is in motion and provides accuracies in the range from 2 to 5 cm. This method of carrier phase positioning is commonly referred to as real-time kinematic or RTK surveying.

A real-time kinematic (RTK) DGPS positioning system is based on DGPS carrier phase technology similar to the kinematic techniques currently used for static GPS geodetic surveys where millimetre level accuracies are achieved. RTK procedures allow for the movement of a GPS receiver after the initial integer ambiguity (i.e., whole number of wavelengths) between satellites and receiver has been resolved, as outlined in Chapter 2.

Accurate real-time elevations (and depths related to the GPS antenna height) can be directly obtained without observing tidal measurement data, if adequate motion compensation sensors are used and project tidal datum modelling has been undertaken (see Figure 7.10).



**Fig. 7.10 “Principle of Real Time Kinematic DGPS elevation determination”**

If elevations are obtained through the use of RTK DGPS techniques, Geoidal-ellipsoidal modelling and tidal modelling procedures are mandatory and should be performed before RTK surveys can be conducted.

### Reference Station

The carrier phase positioning system is very similar to the current code phase tracking technology. A shore GPS reference station is located over a known survey mark tied to the local horizontal/vertical geodetic reference framework; however, the reference station must be capable of collecting both pseudo-range and carrier phase data from the GPS satellites and will consist of:

- a carrier phase dual frequency receiver capable of full wavelength L1/L2 with cross-correlation technique during times of P-code encryption tracking,
- a GPS rover receiver with its associated antenna and cables, high-speed processor and communications link capable of, at least, a 1 second update rate;
- the location will be the same as for a code phase tracking DGPS system;
- the processor will compute the pseudo-range and carrier phase corrections and format the data for the communications link;
- the corrections will be formatted in the RTCM SC-104 v.2.1 format (CMR) for transmission to the rover receiver.

## Communications Link

- a. the carrier phase positioning system requires a minimum data rate of 4800 baud and differs in the volume of data which has to be transmitted from the code phase tracking DGPS system, which requires a baud rate of 300;
- b. this high data rate limits the coverage area for high-frequency broadcast systems;
- c. VHF and UHF frequency communications systems are well suited for this data rate.

## User Equipment

The user equipment on the survey vessel is:

- a. a carrier phase dual-frequency full-wavelength L1/L2 GPS receiver with a built in processor, capable of resolving the integer ambiguities while the vessel is underway;
- b. an associated geodetic GPS antenna, that reduces the effects of multipath on the GPS signal;
- c. a communications link to receive data from the reference station;
- d. the minimum update rate from the reference station to the vessel(s) should be 1 second;
- e. the position output (NMEA 183) carrier phase DGPS data should enable the performance of real-time navigation and recording of the vessel's true position needed for survey processing.

RTK systems are not designed to be used for surveys in excess of 20 km from the reference station.

## Ambiguity Resolution

- a. if the system remains in the RTK mode, real-time sub-decimetre 3D positioning should be available from the rover receiver;
- b. both reference station and the remote station receivers must maintain lock (continuous GPS data) on at least four satellites;
- c. if the number drops to below four satellite, the ambiguities will again be resolved after the system reacquires lock on a sufficient number of satellites, the system will work in DGPS mode or Autonomous mode during this period.

## 4.2 Vertical Control and Calibration

### 4.2.1. General Description

The datum to which depths are to be reduced is fundamental to any bathymetric survey and the Hydrographic Specification will contain full details of how this is to be established together with details of established benchmarks. If the datum is not defined, the existing Chart Datum should be used if at all possible.

The necessity to either establish a new datum or to transfer datum should be carefully considered, any new or transferred datum must be related to the local survey datum through existing or newly established benchmarks, for which full details should be recorded and rendered to the Hydrographic Office. Particular care is required for surveys in rivers and river estuaries; guidance is available in the Admiralty Tidal Handbook Volume 2.

Using the data supplied with the Hydrographic Specification, the location for tidal stations should be determined. If conducting a resurvey, the tide station should be established in the position of the old station if at all possible. If multiple stations are required the distance between stations should not be too great and in any case no more than 10 miles. The Hydrographic Specification will provide guidance on the placement of offshore gauges.

Data to assist in the creation of a co-tidal chart will be included in the Hydrographic Specification. A co-tidal and co-range chart should be produced as described in chapter 5.

Pre-calibrated tide poles and gauges should be established at the desired locations. The tide poles should be connected to the sounding datum via the land levelling system and witness marks installed as a future means of quick visual check on the integrity of the pole. If no local benchmarks are available, for whatever reason, at least 2 new marks should be established and their details fully recorded.

A comparison of tide pole and tide gauge readings over a 25 hour period should be taken to both establish sounding datum on the gauge and to ensure its correct operation. Thereafter checks should be conducted at regular intervals during the survey.

Calculation of Mean Sea Level (MSL) using 39 hours of observation should be conducted at the beginning and end of the survey. Due to daily atmospheric and weather influences, results should be within 0.3 metres of MSL quoted in the Tidal Tables, which will provide additional confidence in the observed tidal data.

When an established gauge is used, the setting must always be checked independently to ensure that the zero corresponds to the stated figure.

Observed tidal data should be inspected each day to ensure that the observations meet the Hydrographic Specification standards. Whenever possible continuous tide readings should be obtained for the entire duration of the survey. Where continuous readings are not obtained, care should be taken at the start and end of each survey period with co-tidal time differences to ensure that the tidal data covers sounding operations.

#### **4.2.2 Tidal Modelling for RTK Surveys**

The survey area must have details of an appropriate tidal datum to meet the requirements of the project to be undertaken. The reason for establishing a tidal datum in the survey area is to update knowledge of MLLW (or Chart) Datum and to enable the benefits of RTK DGPS technology to be realised by performing the survey without using tide gauges.

The main requirements are:

- a. perform wide area GPS static surveys in the selected area;
- b. install sufficient tide gauges in the area to obtain details of tidal datum at these gauge sites computed from long observation periods of data;
- c. perform GPS tidal measurements in the survey area at the same time to obtain a comparable data set of GPS water measurements against conventional tide gauge measurements;
- d. anchor a survey vessel fitted with a RTK Rover Receiver for 25 hour periods in sufficient locations to generate intermediate datum points within the area, to allow correlation between the conventional tide gauge methods and the GPS tidal datum method, and to check any changes in ellipsoid heights between the RTK stations and the gauge sites over a full tide cycle of 28 days;
- e. use a suitable software configuration in the hydrographic survey package which allows for the ellipsoid separation values to MLLW to be used to compute tidal height measurements from the waterline of the survey vessel.

The whole project area must be related to the tidal measurements from the nearest primary tide gauge used to measure the Mean Lower Low Water (MLLW) for the area, also a reference is needed to incorporate tidal datum measurements performed in the survey area. The GPS ellipsoid reference frame and the local vertical datum must be used over the entire survey area.

### **Tidal Datum Diagrams**

Two different tidal data can be realised:

- a. a traditional tidal relationship for the area is represented by the Mean Lower Low Water Tide Surface relative to the local vertical datum, which must provide the MLLW reference with an acceptable tolerance (standard S-44) and should theoretically be parallel to the local geodetic reference surface in absence of currents;
- b. an ellipsoidal tidal datum diagram for the area is represented by the Kinematic GPS MLLW Tide Surface obtained from the ellipsoid height values.

The Ellipsoid Height Surface values and the GPS reference station used to measure the ellipsoid-MLLW separation enables Kinematic GPS hydrographic surveys to be conducted without the use of tide gauges.

### **Location of the GPS Reference Station**

A permanent GPS reference station (Figure 7.11) must to be established close to the shoreline for hydrographic surveys in harbours and related approach channel areas. An antenna height  $h_1$  in meters (negative) should be entered into the GPS receiver during GPS hydrographic surveys. If the GPS reference station antenna is moved, the value is invalid. If the antenna must be moved, the vertical difference  $\Delta H$  between the bottom of the antenna and the reference benchmark must be re-measured and confirmed that the benchmark is (ellipsoid height  $h_2$  in meters) below the ellipsoid. Levelling runs starting from the benchmark should be conducted through the old antenna location and the new antenna location.

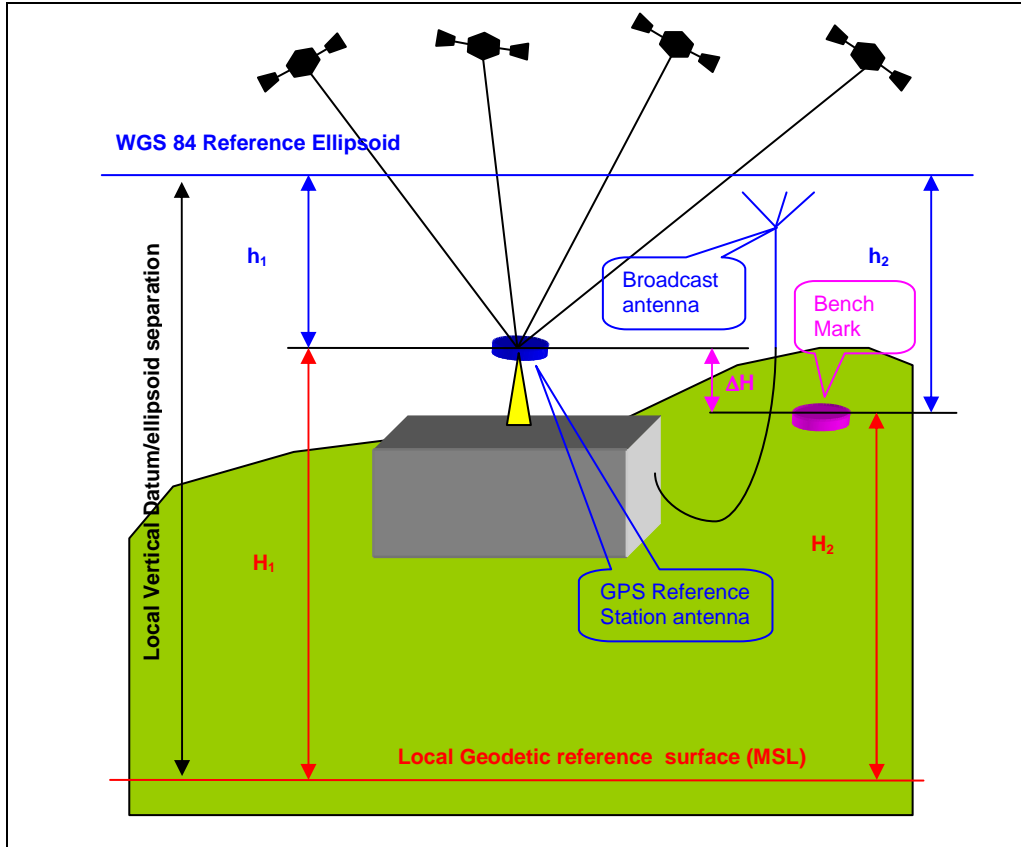


Fig. 7.11 “RTK DGPS reference station parameters”

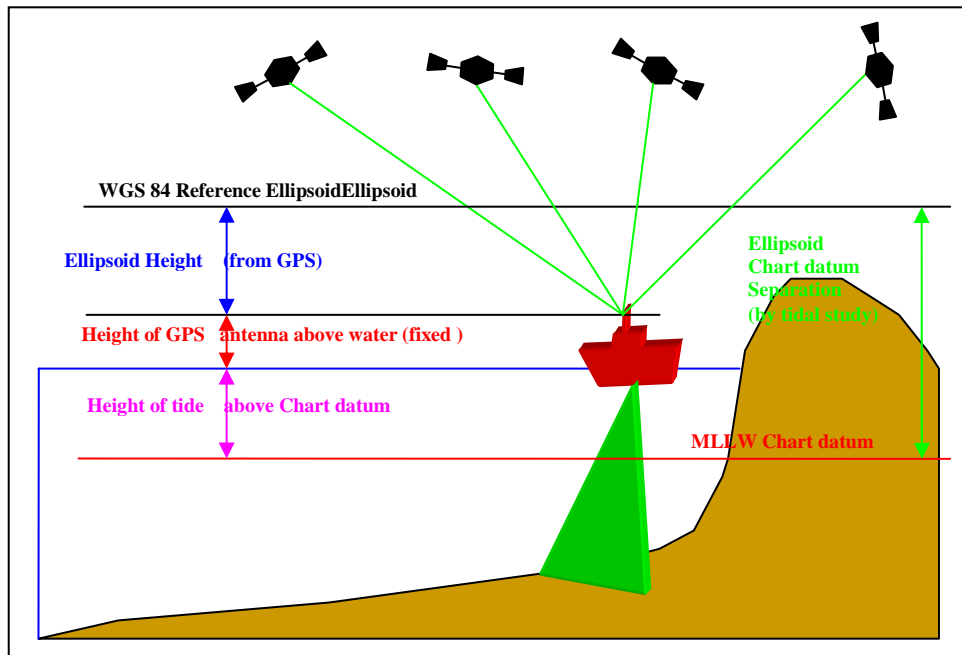
- $h_1$  = ellipsoid height of GPS antenna below the Ellipsoid WGS 84 surface  
 $h_2$  = ellipsoid height of benchmark below the Ellipsoid WGS 84 surface  
 $H_1$  = orthometric height of GPS antenna above Local Geodetic reference surface (VD)  
 $H_2$  = orthometric height of benchmark of the Local Geodetic reference surface (VD)  
 $\Delta H$  = vertical difference between the bottom of GPS antenna and the reference benchmark measured by geometric levelling

### Resultant RTK DGPS Elevation Accuracy

The resultant absolute project accuracy is estimated to be less than 10 cm. The absolute accuracy refers to the MLLW relative to the Local Geodetic reference vertical datum. A local project modelling of the ellipsoid-geoid separation should be attempted for the project. A suitable computer program should be used by entering the surveyed horizontal positions to compute the Local Geodetic reference/ellipsoid WGS 84 separations.

### Real Time Kinematic Measurement at Sea

The GPS antenna phase zero measurement down to the water line of the vessel is the most important vertical measurement on the survey vessel. In a static condition, the measurement is as shown in Figure 7.12. Underway the vessel motion through the water will change these figures, however vessel squat is not entered as a correction in the survey system as the transducer depth is reduced by the same amount the antenna height is reduced.



**Fig. 7.12 “Real Time Kinematic measurement on survey vessel”**

### Survey Procedures, Test and Processing

- a. Conventional method:
  - i. a number of established acoustic tide gauges should be running and downloaded to produce a time series from the data sets, which should be referenced to the station numbers;
  - ii. the gauge data should be used to eliminate actual time differences in the area from average time differences between the gauges;
  - iii. resultant average error when using one tide gauge should be appreciated, the maximum distance at which the data is valid and where it does not exceed standards listed in S-44 5<sup>th</sup> Edition 2008;
  - iv. the separation distance between gauges should not normally exceed double maximum distance highlighted in iii above.
- b. RTK DGPS carrier phase method:
  - i. the use of tide gauges during the hydrographic survey are not required;
  - ii. a MLLW surface should be generated by suitable software from the tidal datum diagram;
  - iii. the survey vessel must be equipped with a GPS Rover Receiver capable of performing OTF GPS carrier phase corrections;
  - iv. vessel data (layout, draft, squat etc) must be obtained from conduct of reference measurements on the survey vessel.

A test on the RTK GPS Tides separation value must be performed, creating a difference ellipsoid/MLLW matrix by suitable software. A sufficient number of cross-section lines must be run in an area between the two nearest acoustic tide gauge sites, which are recording tidal data.

- c. Two survey processing methods are possible:
  - i. the conventional method uses the horizontal GPS co-ordinates only (and not the vertical one) and the reduced depths relative to the MLLW will be obtained applying the tide gage data to the raw soundings;
  - ii. RTK GPS method generates an accurate measurement of depths related to the GPS antenna height without observing tidal measurement data. The GPS depths are directly referred to the Kinematic GPS MLLW Tide surface. A random number of depths from each line should be selected for comparison with the GPS depths reduced by the tide gauge data.

### 4.3 Environmental Observations

The direction and rate of the tidal stream should be observed wherever it is of navigational significance and where there is no evidence that observations have been made previously. Positions, and full requirement, for observations will be articulated in the Hydrographic Specification but additional stations should be included if considered necessary.

Observations should be made using a current meter, current profiler or a floating log-ship. Observations should be made at a depth appropriate to the average draught of shipping using the area or as directed. Observations should not be taken during abnormal weather conditions.

In predominantly semi-diurnal areas, observations should be conducted over a single period of 25 hours at Springs. In areas where the diurnal equality is large, 30 days observations, using a current meters to enable harmonic analysis to be conducted, are required. Should it not be possible for such protracted observations to be taken then sufficient measurements should be obtained to enable a description to be inserted in the Sailing Directions and tidal stream arrows to be shown on the chart.

In addition to standard observations, information of a less formal nature may be available from local sources, especially if it may affect low-powered vessels or yachts. Data obtained should include the estimated maximum rates at Springs and the directions of tidal streams assessed by the best possible means. In areas of strong tidal streams, especially in the vicinity of banks, rocks shelves and in narrow passages, eddies and overfalls may occur which can be of considerable significance especially to small, or under-powered craft. The limits of these phenomena should be fixed, at Springs, on both directions of the tidal stream.

The initial observations of sound velocity should be conducted to allow determination of the spatial and temporal variations across the entire survey area. A grid of observation points should ensure representative sampling is conducted over the whole survey area in a methodical and timely fashion. This data, together with other environmental factors such as climate, fresh water inflow, any seasonal variations and seabed topography, will determine the frequency at which SV profile observations are conducted. The use of moving vessel profilers, undulating profilers and hull mounted probes will reduce the need for static observations to be performed; however water depth and vessel size may limit the ability to make use of such equipment.

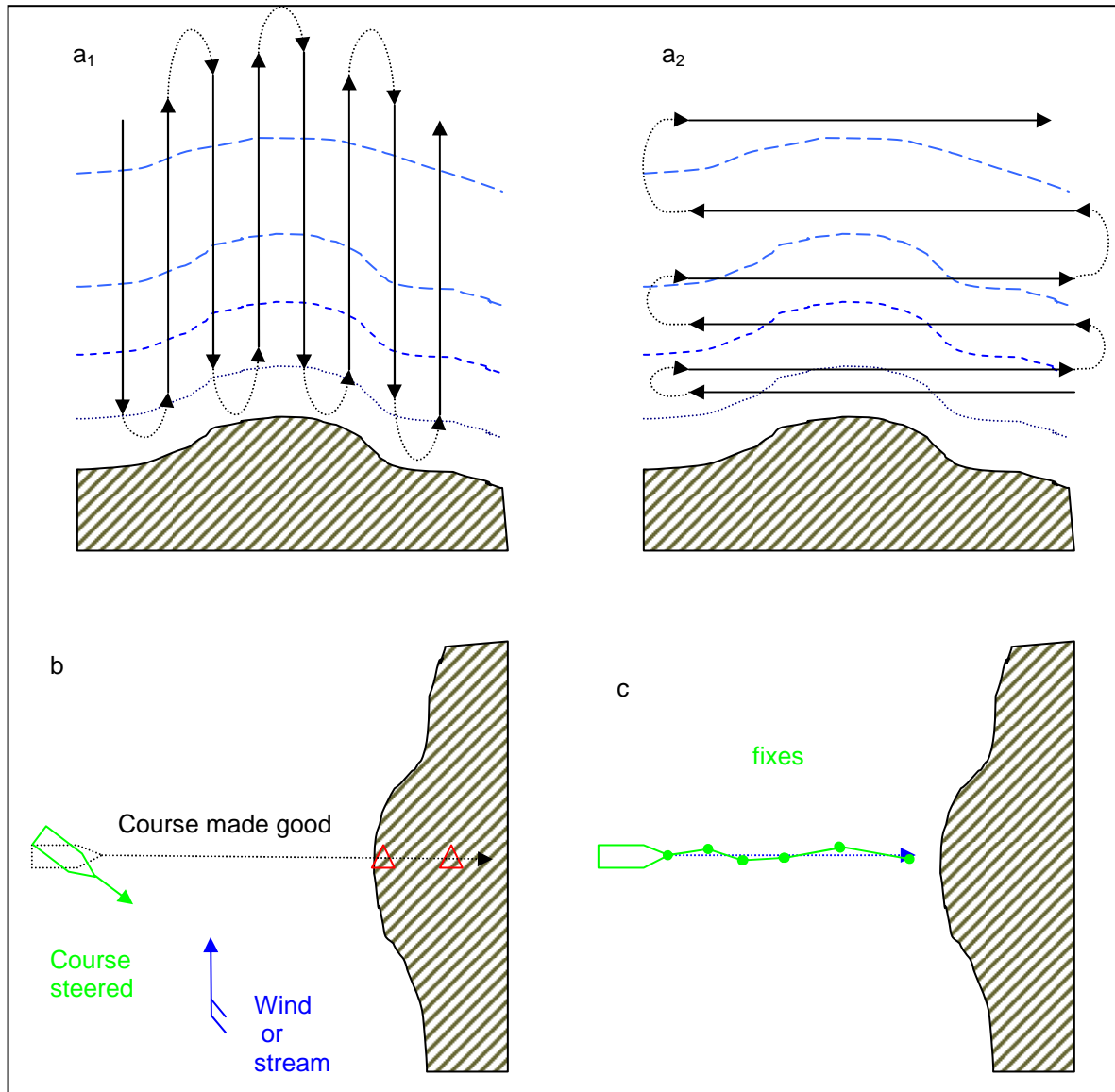
There are set intervals at which SV data should be obtained and applied, guidance should be provided in the Hydrographic Specification and by the Hydrographic Office. The importance of correct SV when using MBES can not be understated.



## 4.4 Line Guidance

### General Description

In positional terms, the process of data acquisition can be summarized in Figure 7.13. Once line data base and direction have been decided the surveyor needs to know his position along the selected line at all times.



**Fig. 7.13 “Sounding lines and related track control”**

- a. The decision on line orientation and spacing for methodical sounding of an area will be influenced by the equipment to be used. Figure  $a_1$  depicts Singlebeam Echo Sounder (SBES) with closely spaced lines crossing the depth contours at right angles, Figure  $a_2$  illustrates Multibeam Echo Sounder (MBES) or Side Scan (S/S) Sonar with lines spaced to have a minimum overlap parallel to the depth contours;

- b. Make good the selected track;
- c. Determine the actual track made good, the vessel's position is fixed at set intervals with the track followed assumed to lie along the line joining the fixes;

A traditional EPS position is updated continually and, by observing a track plotter or left/right indicator, the slightest deviation from the chosen track can be detected and corrected. Further, the track plotter record, if marked to show time intervals along the track, enables the precise plotting of other acquired data. Visual fixes, on the other hand, are periodic events and the assumption that positions at times other than the fix instants will lie on the lines joining fixes will be increasingly erroneous as the interval between fixes increases. Sextant, theodolite, and total station fixes conducted during a harbour survey, may be taken at intervals of a few seconds and the departure from the intended track can be controlled by transit (as is in the above example) or by a variety of other methods.

Modern EPS and satellite fixes are taken every second or less, providing continuous positional information connected to a left/right indicator or to an automated data acquisition system, which offers a means of determining, in real time, the ship's course and speed over ground, with an accuracy directly related to the chosen positioning system.

In surveys of approximately 25 km<sup>2</sup> or less, seabed acoustic transponder arrays, positioned and laid using conventional positioning methods, can be used in conjunction with echo-sounder or sonar ranging to provide continuous positional information and, consequently, control of track.

### **Visual Line Guidance**

When visual fixing methods are used, the ship's track is almost invariably plotted manually, with lines joining fix positions representing the track followed by the vessel. Therefore, the fixing interval and vessel speed are selected that the fixes are sufficiently close (about 3-4 cm. apart on paper) for inaccuracies to be assumed negligible at the scale of the survey (i.e. departures of the vessel from the line joining fixes will be unplotable). Line control during survey operations is usually achieved independently.

In the most difficult case of the off-shore survey with no visible shore control, track guidance will be by compass or better gyrocompass. This is never entirely satisfactory except on very small scale surveys, course adjustment being necessarily delayed until the fix has been plotted. An alternative method of line guidance in these circumstances is to steer the vessel around the arc of a fixed angle subtended between two marks or following a circular/hyperbolic LOP of a traditional EPS chain. These methods are superior to compass/gyrocompass courses but they can be difficult on large scale surveys with shore marks relatively close to the survey area and where the arcs are of small radius requiring constant, large variations of course. Now days, in off-shore surveys, GPS or EPS techniques are exclusively used.

Other methods for visual line guidance and track control are:

- a. Natural transits – by keeping an object near the shore line with another further inshore in the direction of the track to be steered, the helmsman should be able to maintain the line more easily and accurately than by compass course. Any suitable feature may be used (bushes, fence or telegraph posts, huts, parts of buildings etc.), the transit marks should be spaced far enough apart, about one third the length of the survey line, to offer sufficient sensitivity.
- b. Artificial transits – the same principles apply as for natural transits; artificial marks, placed to meet the required line spacing, enable more precise steering and may be essential for large scale work off a barren shore; this method is particularly useful when undertaking large scale harbour and wharf surveys, where transits at right angles can be erected to provide line guidance and fixes at set intervals to meet the survey requirements;
- c. 180° collimator prism – this robust and simple instrument enables the helmsman to sight forward and back marks simultaneously so that, in harbour or river surveys, the vessel can be steered along the line joining points on opposite banks.
- d. Direction from shore – the direction of the intended line is taken off the plot by station pointer as an angle from a reference object or directly from the field sheet by intersection of LOPs of a lattice. The required direction is then observed by theodolite or sextant with the vessel directed along the line by the shore observer using hand flags, lights or radio communications link. When surveying across a river, basin or berthing area, the shore observer can sight an object on the opposite shore on the line to be run, enabling him to follow the vessel's progress by eye.
- e. Starring – by planning the survey lines as radial lines centred on a shore mark, that mark may form the front mark of a transit, the helmsman picking up a new (natural or artificial) back mark for each successive line. Alternatively the “*direction from shore*” method may be used, the shore observer having to occupy only one station. This method is particularly suitable for surveying around headlands and promontories.

### **EPS Line Guidance**

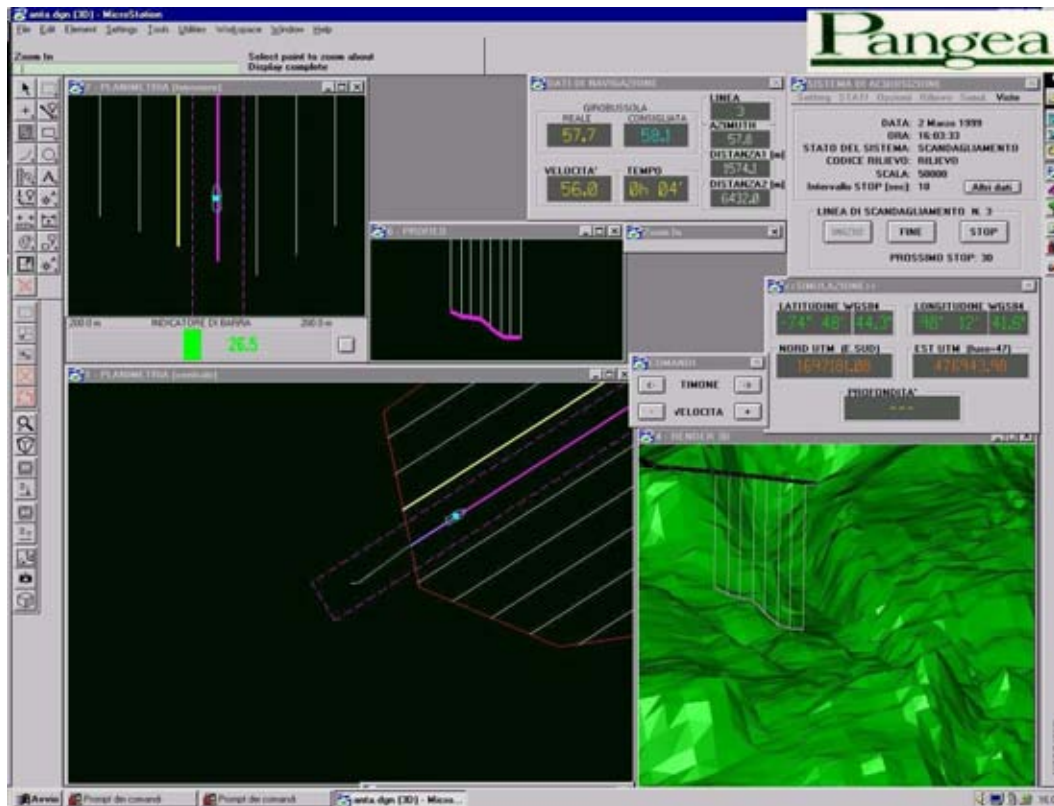
Control may be achieved simply by planning the survey lines along either the range circles or range difference hyperbolae depending on the type system in use. If the lines are steered along pattern lane readings, any departure from the line is immediately obvious, and the vessel may be fixed at the intersection of the line by a second pattern. In a hyperbolic pattern the lines and the fixing intervals will diverge or converge but lane expansion is usually negligible. Allowance may be made for lane expansion, either by changing the pattern intervals used or by running interlines to maintain minimum spacing of lines. A left/right indicator will show the vessel's position relative to the line and provides clear guidance to the helmsman.

Almost all manufacturers of short and medium range EPS systems offer the facility of track plotter as peripheral equipment, which is particularly useful when lines cannot be run along lane boundaries as is often the case in dredging or pipe laying work. The lattice can be plotted out and the selected line followed by a plotter pen, fixes may be marked on the plotter track as a check but it is more usual to keep a separate manual plot since the lattice is often distorted on the track plotter, some types of lattice are shown as a rectangular grid and the required scale of the survey will rarely be that of the plotter.

## Automated Line Guidance

Appendix 4 of Chapter 7 (page 8 and 9) outlines a typical automated hydrographic systems configuration for an Operation Room of a survey ship and the general hardware configuration on a survey boat.

In general the hardware configuration of an automated hydrographic data acquisition system is similar on both survey ship and survey boat, with a suitable hydrographic data acquisition software to control, manage, acquire and store in a specific survey data format digital data from the positioning system and echo-sounder system (SBES/MBES/SSS). Modern hydrographic data acquisition software should provide a helmsman display allowing the vessel to be steered, either manually or automatically, along pre-planned survey lines.



**Fig. 7.14 “Video image displayed from acquisition software”**

Figures 7.14 and 7.15 show some typical video image suitable for a helmsman display providing the following information:

- the survey line followed by the ship geo-referenced with the real time position updated at 1 second intervals;
- a left/right indicator;
- digital information received and managed by the acquisition software (position co-ordinates, depths, COG, heading, SOG, line number and fixes, distances from start and end line, etc.).

All this information allows the helmsman and the surveyor to control and monitor the acquisition process along the selected survey line to cover the area. The acquisition software operator manual should contain all the instructions and procedures to manage the automated track control, which in general is conceptually similar for every software manufacturer.



Fig. 7.15 “Video image displayed from acquisition software”

#### 4.5 Check Lines

Crosslines should be run, at the beginning of the survey, perpendicular to the main sounding lines and, whenever possible, at a different stage of the tidal cycle and in good sea conditions. Sufficient sonar information from crosslines should be gathered to enable a statement to be made in the RoS of the extent of sand ripples in the survey area and their direction.

Sounding crossovers should be compared as the survey progresses as a check against gross errors, co-tidal modelling error or equipment malfunction. On-line MBES displays should be used to verify the repeatable performance of sounding by monitoring adjacent swathes; this should also be used to ensure that the coverage and swathe overlaps are being maintained, additional lines should be run to fill any gaps in coverage.

#### 4.6 Main Lines

The sonar sweep type should be articulated in the Hydrographic Specification, which should also detail the % coverage, % overlap and object detection criteria to be achieved. Careful inspection of the Hydrographic Specification limits and those of adjacent modern surveys is required to ensure that there are no gaps between them.

When conducting sonar and sounding lines concurrently, a careful balance must be maintained between the conflicting requirements. Every effort must be made to ensure that there are no gaps in the sonar sweep and therefore it will generally be necessary to subordinate the needs of bathymetry to those of sonar. Additional sounding only lines may be required to assist with the delineation of contours and critical features, where line keeping error is >25% of line spacing, the gaps should be filled with additional lines.

An *a priori* sounding error budget/estimation should be created and compared to the Hydrographic Specification requirements. If significant environmental variance is encountered or changes to equipment are made to those initially used, the error budget/estimation process should be repeated and these new results used as the basis for comparison.

Main survey line spacing, direction and sounding speed should run to meet the requirements of the Hydrographic Specification and the laid down criteria. The optimum and maximum survey speeds should be assessed taking into account the depth range and systems in use for the survey; the maximum ping rate and range scale should be utilised commensurate with the depth of water. Normally sounding lines should be run perpendicular to the general direction of contours; however sonar lines should be run within 20° of the prevailing tidal stream or current. In areas of strong tidal flow, a direction much less than 20° may have to be adopted to ensure that the sonar towfish follows the ship's track.

When surveying with MBES only, line orientation and spacing will be dictated by the criteria detailed in the Hydrographic Specification and the customer requirements. Object detection and thus data density will determine % overlap between adjacent swathes, which will be a function of water depth; thus line spacing will be influenced by water depth, data density and objection detection criteria and % overlap, which will give the % coverage achieved. It is most likely that line spacing will vary across the survey area, particularly if there are marked differences in depths; careful monitoring during survey operations will be required to ensure the desired objectives are being met.

Fix interval and logging intervals should be set as required by the scale of the survey and the survey processing system in use.

When using SBES, additional sounding lines should be run at standard spacing perpendicular to the contours from the 10 metre contour into the shore in order to determine the 5 and 2 metres contours and the drying line. Additional lines should be run parallel to and at distances of 2, 5 and 10 metres off jetties or wharves.

When sounding over sandwaves, operations should take place following periods of calm weather and neap tides when sandwave amplitudes are greatest. Where possible re-surveys of sandwave areas should follow the same tracks to detect changes in sandwave profiles.

Care should be taken delineating the drying line, particularly with regard to off lying banks, rocks and shoals, as the position of such features may have international legal implications. When surveying within harbours and boat havens, drying heights and the location of foul ground, in areas where small craft anchor or take the ground, should be accurately delineated.

Whenever a survey includes a channel, recommended track or leading line in restricted waters, it should be swept by sonar. Allowance during such sweeps should be made to accommodate the largest vessels likely to use these tracks paying particular attention to turning areas and where a track changes course.

Regular checks should be conducted to ascertain sonar performance, suggested occasions are:

- a. On first streaming;
- b. Once per day when operating in areas of featureless seabed;
- c. After maintenance or repair;
- d. After changing towfish or fins;
- e. If the performance is in any doubt.

If it appears that the sonar system is not working to its maximum range, due either to water conditions or to material inadequacies which cannot be rectified, the sonar sweep should be modified to ensure complete coverage.

A magnetometer should be deployed throughout the basic sonar sweep to provide additional evidence of the existence of ferrous metal on or below the seabed.

It is of utmost importance that the sweep is thorough, that no gaps appear in it, and that every significant seabed feature or artificial obstruction is located.

#### **4.7 Inter-lines and Investigations**

Items in the supplied list of wrecks requiring a disproving search should be searched for out to a radius of 2.5 miles from the listed position. The limit of the area of this search may extend outside the given limits of the Hydrographic Specification; however such an extension is essential to avoid the anomaly of having a PA wreck lying inside an area considered to be fully surveyed. Ensure that any disproving search areas lying on the outer edge of the survey area are covered; additional lines should be planned to run outside the area in order to ensure complete insonification of the area with an appropriate overlap.

Careful note should be taken of the 500 metre safety zone around seabed installations and pipe laying operations when surveying in or near oilfields or exploration areas to ensure the safety of any towed equipment.

For an object charted PA, the sonar search should be conducted in 2 directions at right angles and extend to at least 2.5 miles from the datum position. If there is a high degree of confidence that the initial search in one direction was entirely thorough and that the sonar equipment was operating satisfactorily, consideration may be given to dispensing with the search in the second direction.

Objects whose positions have been previously established, but which cannot be found during the survey, need a very detailed investigation to disprove them. Where such objects fall within the survey area and a sonar search is completed to a radius of ½ mile around the listed position, this will be considered sufficient. A magnetometer should also be deployed. When there is no doubt about the geographical position of a wreck after many repeat surveys, the above radius may be reduced. Consideration should be given to the use of a wire sweep.

Each contact should be closely examined using sidescan sonar; should the contact be confirmed, its position and least depth by close sounding should be established. A minimum of 4 good runs, comprising 2 perpendicular pairs, should be achieved. In the case of wrecks, one pair of tracks should be parallel to the axis of the wreck and one pair perpendicular to it.

Data regarding the contact can be obtained from the use of sonar, echo sounder, magnetometer, wire sweeping, diver or a combination of these. Each contact should have the following detail:

- a. Position;
- b. Least depth;
- c. Nature of the object;
- d. Length, breadth and orientation;
- e. Depth, length and orientation of scour;
- f. Debris field length and orientation;
- g. Strength of magnetic field.

Examination of the supplied wreck list may aid identification of the object; however caution should be exercised in too freely linking newly discovered wrecks with those contained in the wreck list. Disproving searches may still be necessary in charted positions. The use of divers may be helpful in identifying wrecks and reporting their state and attitude; in particular, they may be able to locate high points, which may not have been distinguished on the echo sounder or sonar.

The least depth over wrecks and obstructions must be established, in certain circumstances this will require the use of wire sweeping, which should be conducted after the position, size, orientation and probable least depth have been determined by sonar and echo sounder. Wire sweeping should be considered in the following circumstances:

- a. As directed in the Hydrographic Specification for specific wrecks;
- b. If the least depth is likely to be less than 40 metres;
- c. Where depths around the wreck are significantly different from those charted;
- d. When salvage/dispersal work has taken place since the last survey;
- e. Sonar indication of protruding masts and structures;
- f. Areas charted as foul within an anchorage;
- g. Wrecks in areas of strong tidal streams and seabed mobility;
- h. Where the position of the wreck is significantly different from that charted.

Care should be taken to ensure that the whole area of the wreck is covered by the wire sweep, albeit in several laps, and that there are no gaps between the sweeps. It is not sufficient to cover only the areas which appear to be high points on the sonar.

Particular attention should be paid to the sounding of depths <40 metres, where the least depth should be obtained over all seabed features. Interlines should be run in depth <40 metres unless the seabed is flat and featureless and no dangers are shown to exist by complete coverage by high definition towed sidescan sonar or MBES.

#### **4.8 Ancillary/miscellaneous Observations**

Seabed samples should be obtained at regular intervals throughout the entire survey area. Additional samples should be taken in all likely anchorages, on all banks, shoals and seamounts, particularly where these are likely to be unstable, and in the channels between them. Approximately 10% of the samples obtained should be retained for rendering with the final survey.

Seabed samples should normally be obtained throughout the survey area prior to commencing the area sonar sweep to provide a method of ground truthing the sonar picture and to enable more accurate interpretation for seabed textures.

Before arrival in the survey all fixed and floating navigation marks and aids should be identified from the largest scale charts, List of Lights and List of Radio Signals. On arrival all uncharted or listed navigation marks and aids should be identified.



The position of each new fixed or floating navigation mark and any suspected of being out of their charted/listed position should have its position determined; floating marks should be fixed on the full ebb and flood tides, however if an unambiguous position of the central mooring sinker/anchor can be obtained from swathe bathymetry, it is permissible to quote this as the charted position.

For lit navigational aids the following should be recorded:

- a. The height of the focal plane;
- b. Light and sound characteristics;
- c. Light sectors and obscured arcs;
- d. The structure shape and colour;
- e. The top mark shape and colour.

Colour photographs of all marks should be taken for inclusion in Sailing Directions.

Harbour authorities should be consulted over changes found to nav aids to determine if such changes are permanent or temporary. Details of any planned changes should be obtained.

The details of port radio operations, including Ship Reporting Systems (VTS, VTM, VTIS, etc), radio pilot services, radio navigation aids (including (Aero) radio beacons, radar beacons, etc), coast radio station services (ie. public correspondence details, navigational warnings and weather information broadcasts, schedules, etc), GMDSS facilities, together with Search and Rescue procedures, are to be obtained.

Every opportunity should be taken to obtain details of natural phenomena during the course of the survey. Such phenomena includes:

- a. Deep scattering layer is the biological layer, consisting of plankton, and other small marine organisms, and the larger fish that feed on them. Certain of these have swim bladders which respond to echo-sounder and sonar transmissions, causing scattering of the sound waves, which may have considerable affect on sonar operations. Reports of the phenomenon are therefore important and should be rendered;
- b. Marine bioluminescence is caused chiefly by marine animals varying in size from microscopic organisms to quite large fish, squid and jellyfish. It is more commonly encountered in warm waters than in cold, and is of considerable interest to marine biologists and military scientists. Reports on the phenomenon are therefore important and should be rendered;
- c. Discoloured water is generally recognised to be almost always biological in origin. Water samples and secchi observations from such areas are of considerable interest and should be obtained and reported;
- d. Marine life reports should be made to cover whale movements and those of other marine mammal species, which are of considerable interest in anti-submarine warfare and to marine biologists. The presence of commercial fishing activity in the survey area is of importance as the sound generated by engines and deployed fishing gear may significantly affect ambient noise levels. Also the occurrence of a fishing fleet may indicate the presence of large fish populations; sound scattering caused by shoals of fish may inhibit sonar performance. Sightings should be included in the RoS.

## 5. COASTLINE DELINEATION

### 5.1 Coastlining General

The accurate delineation of the coastline (shoreline) and coastal features is an essential feature of a Hydrographic Survey, since the mariner is often required to fix his position by bearings and angles or ranges to promontories and similar features on the coastline. Generally, in hydrographic surveying, the coastline is defined with respect to a HW datum.

The coastline, except in the most rapid and cursory surveys, must always be walked over in the field when its nature permits. Many small river mouths and streams have been missed by the practice of taking a boat along the coast and only landing at various discreet locations.

In some instances, adequate land survey maps based on modern air photography or satellite imagery will provide data which can be used to assist in plotting the coastline. Occasionally air photography will be flown specially for a survey and an air “photo plot” produced at the appropriate scale. This however does not obviate the need to walk the coastline in the field.

All land survey maps and air photo plots should be checked in the field before use is made of them on the Bathymetric Sheet and Tracings to Accompany. Where no maps are suitable, the coastline must be properly surveyed with key features being fixed by a regular method dependant upon the scale of the survey.

A surveyor delineating the coastline, even when checking a map or photo plot, should plot the Drying Line as best as possible and should always note the nature of the foreshore. The best way to find the Drying Line is by reduced soundings but every part of the foreshore should, if possible be seen at least once at low water in order to see whether there are dangers which might have escaped attention. This is particularly necessary where the range of the tide is great.

### 5.2 Coastal Details Required

The surveyor should carry out the following tasks:

- a. Delineate and fix the coastline by the best methods available;
- b. Fix and describe all objects CONSPICUOUS and Prominent to the mariner, which are not already fixed, and check existing marks/features on charts and publications are positioned and described correctly, even though they may be a little inland;
- c. Fix and describe or indicate on the chart all objects and features of the coastline which would assist the mariner to fix himself and identify the coastline. In large scale surveys this will include very minor detail which can only be seen close inshore;
- d. Measure and estimate the heights of all such features, some features can be described in general terms such as “Low red cliffs, 5 to 6 metres high”;
- e. Fix all islands, visible offshore dangers and obtain their heights, also fix adjacent floating marks (buoys not on chart);
- f. Describe the composition of the beach between the low water line (drying line) and the high water line as well as above the high water line. The appropriate symbols should be inserted on the Bathymetric Sheet;

- g. Indicate established landing places along the coast. Fix and describe groynes, sewer outfalls and anything that might constitute a danger to landing. Piers and jetties should also be fixed and a full description obtained, which should include type of structure, depths alongside, height of deck above the HW datum and facilities available;
- h. Details of harbours should be obtained giving berthing facilities and supplies available, this information is to be included with the Sailing Directions;
- i. Where appropriate, correct spelling of place names should be obtained from reliable local sources and checked with names shown on existing maps and charts & publications.

In addition the surveyor may concern himself with topographical detail near the coast. The amount of detail will depend on the time available, the scale of the survey and whether topography is going to be obtained by another field party or by other means, such as air photography.

### **5.3 Detail Of Concern To The Mariner**

CONSPICUOUS objects/marks. - Mariners use bearings to peaks, churches, chimneys, windmills, masts, permanent buildings etc. They will be visible from quite a distance offshore.

Prominent marks. - Again, Mariners will use bearings to peaks, churches, chimneys, windmills, masts, permanent buildings etc. These marks will be visible from quite close to the foreshore/coastline.

Headlands, Islands, Offshore features. - Mariners use bearings to left and right tangents and vertical heights to cliff tops etc.

Harbour and Port facilities. - Determine dimensions and heights of jetties, orientation and depths alongside, type of construction, mooring and berthing facilities, small craft facilities, visiting craft details, marinas, yacht clubs, fuelling berths etc.

Principle Land Features:

- a. Natural Objects - Hill summits, rivers, lakes, marshes, woods, contours etc.
- b. Artificial Objects - Buildings, towns, flag staffs, roads, railways, factories etc.
- c. Contours - Sufficient to indicate height and shape of coastal region.
- d. Nature of the Foreshore and Near shore Topography - To assist in recognition and in selecting landing places.

Lights. - Details must be checked in the field and against entry in Light Lists.

Sailing Directions. - Full written descriptions of the coastline and details of port and harbour facilities.

### **5.4 Topography**

Where recent land surveys maps, aerial photographs or plots from photographs are available, they should be thoroughly checked in the field and any discrepancies recorded.

The topography shown on large scale charts should be also be checked in the field to update detail which is not normally shown on maps and which is not visible on aerial photos, paying particular attention to coastal details e.g., beacons, flag staffs, groynes, etc. Charted objects which no longer exist should be recorded, preferably as deletions on a copy of the chart, which should be forwarded with the results of the survey.

No topographic detail is to be shown on the Bathymetric Sheet unless it has been surveyed in the field, or its existence and position on a map or air photo plot have been confirmed by the surveyor. Newly surveyed detail must be included, detail from other sources which is found to be correct may be transferred to the Bathymetric Sheet, at the surveyor's discretion to give a balanced, more complete presentation, but it must be inserted with meticulous care so that subsequent queries concerning its authenticity do not arise.

Where no modern maps or air photography exist, all topographical detail which will be of use to the mariner must be accurately fixed and shown on the Bathymetric Sheet. In particular, all features that may be used to fix a ship's position, whether visually or by radar, should be plotted and, where practical, coordinated. Unless time and resources are available, effort should not be expended in recording minor topographical detail of no direct interest to the mariner, or which is not visible from seaward.

Any changes that are found should be reported.

### **5.5 Delineation Of The Drying Line**

The drying line is in general the basis for determining the limits of the territorial sea and associated baselines and its careful delineation is most important because of the affect it may have on fishery limits, observance of pollution regulations and the licensing of offshore mineral extraction, as well as on the delineation of international boundaries. Surveyors should therefore take special care that the drying line of the mainland, islands and of all drying features, is adequately delineated even though it may be of little interest to the mariner.

The survey of an area involving drying features must be considered incomplete if the drying line is not adequately delineated, unless specific instructions are issued to the contrary.

### **5.6 Heights Of Land Features**

The height of all land bordering the coast must be obtained even if the elevation is small, in particular every small islet and rock which shows above water must have its height noted against it. If there are no summits available, the heights of the tips of tree or islands must be found and recorded. Similarly the height of all tall artificial features such as masts, chimneys etc.

Cliffs must have their heights noted, and their colour if in any way remarkable.

Heights of objects should be referred to MSL (or its equivalent), if this is impractical, the actual height of the object may be shown as a legend. For special purposes or in river surveys, other criteria for the reference plain may be used.

### **5.7 Charting The Foreshore**

The main concern when charting the foreshore is to fix the position of all dangers which may have been missed by routine sounding, such as rock outcrops or man made obstructions. Objects that lie beyond the drying line will have to be intersected. Pipelines or cables prominent on the beach may extend out to sea beyond the drying line and be a hazard when anchoring. Finally the nature of the foreshore should be recorded.

## 5.8 Coastline Overlay

A properly prepared coastline overlay should contain:

- a. Title of the Survey. Survey specification number, scale, ship's name and any other subsidiary identification;
- b. Position of all co-ordinated marks to be used;
- c. Grid and Geographical positions pricked and circled in ink with value of at least 2 of each positions;
- d. Diagonal scale;
- e. True and magnetic meridians;
- f. A note of the value of least plottable distance, which is  $\frac{1}{4}$  mm on paper, regardless of scale (1 : 10 000 =  $2\frac{1}{2}$ m).

## 5.9 Use Of Air Photo Plots

An air photo plot of the coastal area within the limits of a Hydrographic survey will sometimes be prepared in the Hydrographic Office when:

- a. Existing mapping of topography is outdated, poor or non-existent;
- b. Features of hydrographic interest, eg underwater rocks, are either shown inadequately, or not included, on topographical maps, and are evident on photography held;
- c. Drying heights can be accurately and efficiently established by photogrammetric means.

When an air photo plot has been supplied in support of a survey specification, the following procedure can be adopted:

- a. The photo plot is to be thoroughly checked in the field for errors in photo interpretation, shape and position. Difficulties experienced in photo plot compilation and discrepancies with existing data, will be highlighted in the photo plot report that accompanies the photo plot. Special attention must be given to resolving these differences;
- b. Data on the photo plot which has not been verified in the field must not be included on the Bathymetric Sheet. It should be noted that the water line derived from air photographs rarely coincides precisely with Chart Datum, especially in areas with gently sloping beaches and there may be a need to adjust it before insertion on the Fair Sheet;
- c. Amendments to the photo plot must be shown by marking corrections on a copy of the photo plot;
- d. When required, air photographs supplied with the plot are to be marked by pricking and identification on the reverse side, to show additional control established for the survey.

Existing air photography can be of considerable use in coastline delineation. Previously used ground control points should be checked against the survey reference system, remembering that the flight scale may need to be expanded to 4 or 5 times to match the survey scale. Note that ground elevation errors in photogrammetry are about  $1/5000$  of the flight height whilst horizontal errors are considerably smaller.

When coastline delimitation is the objective, rectilinear strips orientated parallel to the coastline should be planned. Overlapping strips should include common control points and the flights should co-inside with low water times.

For large-scale surveys (less than 1 : 50 000) where photogrammetry will be used to obtain ground relief and other topographic details, additional 3d control will be required. Errors in co-ordinated ground control points should less than half the aerotriangulation errors for points used during photogrammetric interpretation.

For strip aerotriangulation adjustment, 4 planialtimetric (3D) control points are required. Further inner control points should be added to each strip.

In more complex flights with a large number of parallel strips, the aerotriangulation enables a block adjustment to be made. The planialtimetric ground control points may be in the order of  $5+0.2M$  (where  $M$  = the model number of the aerotriangulation process). Additional altimetric control points may be required in areas where accurate heighting of features is required.

For smaller scale surveys (greater than 1 : 50 000) a lesser number of ground control points will be required, some with only horizontal co-ordinates known. This is also true for satellite imagery.

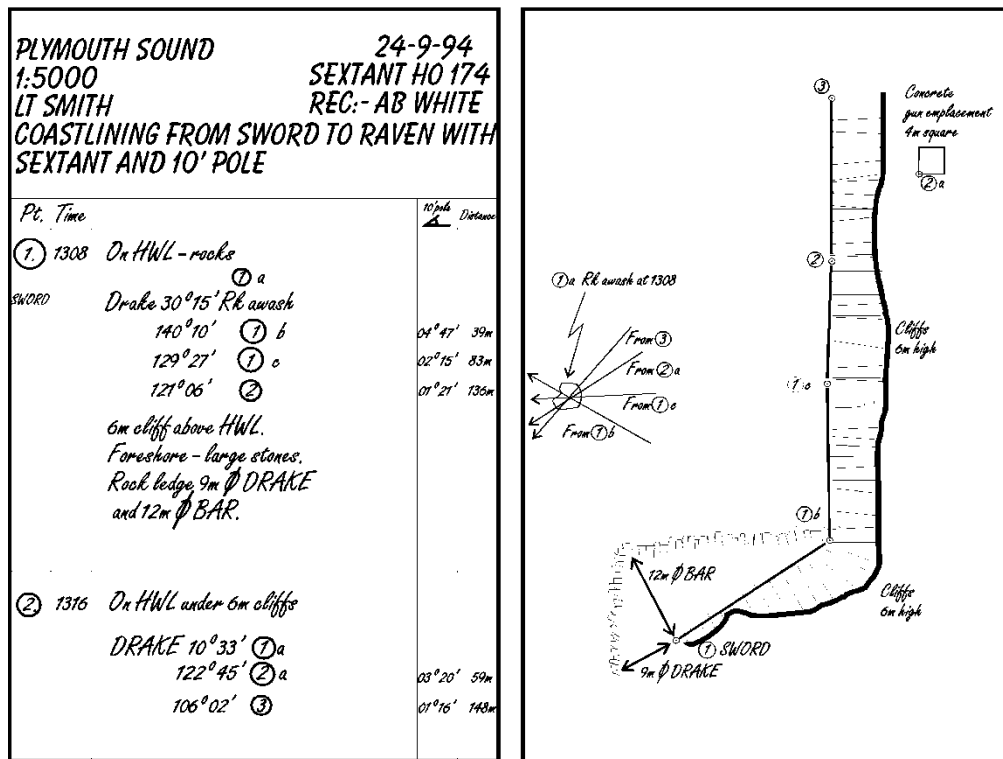
Photogrammetry or satellite imagery does not negate the need for the surveyor to fully explore the coastline in the field.

### 5.10 Coastlining Methods

Whichever method is used, points must be fixed on the HWL so close on paper that detail can accurately be drawn in between them. Spacing on paper depends, therefore, on the complexity of the coastline.

Typical recording for a traverse using sextant and 10' pole is detailed below. Similar recording would be employed when resecting, or using a combination of both methods. Note the diagram shown embraces all angles and distances on the recording page.

(Opposite page)



### 5.11 Plotting The Coastline

It is usual to draw the coastline by plotting the resection fixes or traverse points directly on to a coastlining overlay, although a millimetric plotting sheet may also be used. It may also be appropriate to compute the turning points of a traverse and to adjust them prior to plotting. Prick through known co-ordinated points used to start and close the traverse, the remaining coastline details are then plotted by hand.

The graphic method of plotting a coastline is given below:

- a. Plot the points by protraction of angle and distance. It will be found most convenient to use a large circular protractor of transparent plastic, springbow dividers, prick and well sharpened 4H pencils. It is important to remember to avoid the use of short zeros on the paper for aligning the protractor. When plotting rays, ensure that they are drawn longer than required and that prick holes made at the edge of the protractor are marked so that they can be used again for aligning the protractor if required. It is important to do this when the reference object is the back mark of the traverse and therefore the zero for plotting would be very short if the back mark prickholes were used for aligning the protractor or station pointer. If there is an acceptable misclosure the traverse should be adjusted graphically. If there is a large misclosure it will often be found to be due to a single gross error rather than an accumulation of minor ones. The plotting should be checked carefully before abandoning hope and re-surveying the section in the field;
- b. The intermediate points, tangents and plotting shots are then drawn in from the corrected positions of the turning points; care must be taken to zero on the corrected positions of the back marks, drawing lines through them upon which to align the protractor;
- c. The detail of the coastline between the intermediate points is then inserted using the sketch map; air photographs and existing maps are of great assistance as is the information noted at the ends of lines by boat-sounders;
- d. The coastline is then inked-in using the appropriate colours and symbols (see Int 5011). When depicting cliffs or steep coasts, the base of the cliffs must be correctly charted but the tops can be drawn far enough inland to permit the pen work to be inserted; similar exaggeration is necessary with certain other symbols but great care must be taken with those representing low water features to ensure that the seaward limit is correctly charted.

### 5.12 Coastline Delineation Report

Coastline survey work should be reported in accordance with Appendix 2 to this chapter, however some of the more important aspects are detailed below:

- a. State the aim of the work, noting whether it was to update an existing chart, for a new chart or another special purpose. Indicate what other sources of material were used in addition to field observations by the surveyor on the ground;
- b. A brief summary of the methods used and the measurements taken to establish control for the coastline survey, including any air photo control points;
- c. Highlight any particular difficulties encountered and any additional work required; provide an indication for the time scale before resurvey may be necessary;
- d. Provide an assessment of the co-ordination errors of surveyed objects and marks;
- e. Describe all new control points established with an indication of life expectancy, detail previous control points reoccupied and assessed material state; full station descriptions should be rendered for all points;

- f. Comprehensive details of the results obtained should be rendered; all plots, photographic views, video records, harbour and port information reports, samples obtained and survey records to be rendered should be listed;
- g. The sources from which names have been obtained should be reported, if locally produced modern maps have been used to confirm names, copies should be forwarded with the Report of Survey;
- h. The survey should comment on the completeness of the survey and indicate where further work is required.

As with all survey records, it is vital that all coastline survey records are cross-checked to ensure no anomalies exist and that consistency between quoted details is achieved. All records to be rendered must be carefully checked and listed to ensure a clear understanding of the survey can be generated back at the Hydrographic Office.

## **6. DATA PROCESSING**

The care and attention devoted to work in the field must be extended to all aspects of data processing and to the careful and legible annotation of all original material used to generate the final records. The underlying principle to be observed in compiling records of any survey is that they must be entirely intelligible to any person having a sound knowledge of the type of survey concerned. The preparation of all data in the established manner, neatly, concisely and accurately, is absolutely vital; terminology should be in accordance with the definitions in IHO Publication S-32.

### **6.1 Bathymetric**

The output of the bottom detection process, when using MBES, is an accurate time and angle of arrival for each measured depth. These 2 parameters are used as inputs to the ray tracing algorithms which convert them into an accurate depth and along/across track distance using information about the SV profile to make the calculation, which is normally carried out in near real time.

The sheer volume of gathered data with MBES invariably means that area based processing is the only realistic method. SBES can be processed in a similar manner, however line-by-line processing with direct comparison against the echo trace, if generated, is often more appropriate.

The use of satellite navigation systems has reduced the amount of post-processing and track editing necessary, however careful online QC of the navigation system output and statistics is vital to ensure that the positional standards are achieved.

SV column profile data should be obtained at regular intervals during survey operations, particularly if continuous SV observations are not being acquired and applied. The interval between SV observations will be determined by the environmental dynamics assessed from the initial temporal and spatial data obtained in accordance with paragraph 4.4.5.

All algorithms used for data editing should be recorded and included in the RoS to enable a clear understanding of the processing procedure to be gained by the Hydrographic Office. The smoothing and filter parameters may be detailed in the Hydrographic Specification or standardised by the Hydrographic Office, any variations should be justified in the RoS. Excessive filtering and smoothing should be avoided.

The editing and processing procedure must follow a logical path with a clear audit trail to enable all actions and parameters to be checked and approved, a robust QC routine must be in operation throughout, which should allow for comparison against previous surveys, published charts or validated survey data, and against



recently obtained adjacent survey data. Careful inspection of the crossline/checkline data should be undertaken, a statistical plot should be produced and any differences  $> \sqrt{2}$  x sounding error budget should be investigated.

Observed tide gauge and pole readings should be reduced to sounding datum at the tide station using the values obtained for each when they were installed. Any co-tidal time and range factors should be applied to reduce the observed tides to the values at the survey area.

A daily comparison of the tide gauge and tide pole should be carried out by comparing simultaneous readings. After reduction to sounding datum, simultaneous tide pole and tide gauge readings should be compared to ensure that the tide gauge was recording correctly.

Reduced tide gauge readings should be plotted and the resulting tide curve compared to the predicted curve at the tide station to ensure consistency of data and to ensure that the tide gauge was recording correctly. Unless 'steps' in tides are expected, curves may be smoother, large or repetitive steps should be noted in the RoS and the tide gauge checked for any malfunctions.

When using telemetry links with established gauges, a comparison of actual gauge and telemetry values should be conducted during the 25 hour pole/gauge comparison and then at intervals throughout the survey.

Data density should be aligned with the object detection requirements, which will determine the grid size to be used. In surveys for navigational charting, shoal bias is the normal criteria; however there are occasions when mean depth will be appropriate. The Hydrographic Specification and the Hydrographic Office policy should provide guidance on the requirements.

The Hydrographic Specification should detail the final survey product presentation including contour intervals; however full use should be made of the numerous visualisation tools available to aid in the checking and QC of the survey. Some of the visualisation formats are:

- a. Sounding plots;
- b. Contour plots;
- c. Digital colour sounding and contour displays;
- d. 3D colour depth surfaces;
- e. 3D grey scale sun illuminated surfaces.

If 3D grey scale sun illuminated surfaces are created, the surface should be viewed from 2 perpendicular directions to highlight any anomalies or artefacts which may need further investigation.

Note should be made of all features and least depths for comparison against sonar records, if obtained. In any event, an assessment should be made as to whether further investigation is required.

## **6.2 Seafloor Characterisation**

The texture data deduced from the sonar trace or backscatter data will be merged into a mosaic either using an automated system or by creating a hand drawn seabed texture collector. In both cases interpretation will be guided by the grid of seabed samples taken earlier in the survey.

Initial detail should include the crests of sandwaves with heights, the positions of obstructions with heights and the start and end of rock outcrops and pinnacles. Texture detail should be plotted to define the limits of texture boundaries. Care should be taken to ensure conformity of texture details to previously survey areas.

Instances will occur when additional seabed samples are required to clarify complex seabed texture areas. Sufficient additional seabed samples should be obtained until confidence has been achieved that the seabed has been accurately classified.

The quality and totality of sonar coverage should be determined by inspection of:

- a. A plot of the ship's track, inspection will reveal any gaps in coverage due to poor line keeping or excessive towing speed, these gaps should be re-run;
- b. Line quality control data which will indicate whether the maximum tow speed has been exceeded, areas of excessive should be re-run;
- c. Sonar traces should be inspected to ensure that the towfish was deployed at the correct height above the seabed and that good data was being recorded, any areas with suspect data should be re-run.

### **6.3 Feature Detection**

Wreckage or artificial obstructions which stand proud of the surrounding seabed may constitute a hazard to shipping or to submarines navigating over continental shelf areas. All such objects must be located, examined and recorded.

During the initial sonar sweep of the area, sonar traces must be carefully examined and all contacts likely to represent obstruction carefully noted. Contacts should be recorded methodically recorded:

- a. Sonar trace number;
- b. Julian day and time;
- c. Contact number (should be consecutively through the survey);
- d. Fix details;
- e. Port/Starboard channel;
- f. Slope range;
- g. Layback;
- h. Height of towfish above seabed;
- i. Assessment of contact;
- j. Further action required (ie. investigate, interline, quick look, no further action).

The magnetometer trace and depth data should be carefully examined to provide supporting evidence.

On completion of an examination the records should be carefully checked to ensure that the process has been conducted thoroughly. The following points should be considered when assessing the thoroughness of a examination:

- a. As long as a wreck, foul or obstruction continues to be a hazard to navigation or other marine activity, it must appear on the chart;
- b. Any objects described as giving 'non-sub' echoes or which constitute a 'foul' on the seabed must be found, classified, fixed and recorded; whether dangerous to shipping or not, they must be disproved;
- c. The onus is to classify or disprove every charted wreck, foul, obstruction or contact previously described as 'non-sub'; unless disproved beyond doubt, they must remain on the chart.

The satisfactory examination of every significant object located during a survey is a major factor in deciding whether an area has been fully surveyed.

#### **6.4 Ancillary/miscellaneous Observations**

Tidal stream, gathered during the survey via whatever methods, should be assessed for validity and consistency. Where previous tidal stream data exists, the new observations should be compared to ensure continuity and uniformity. Where no previous data exists, observations should be inspected to ensure that they are in agreement with tidal streams experienced during the survey, which can be assessed from comparisons between the courses and speeds set against the courses and speeds made good.

It is usual for the analysis of observed tidal stream data, for inclusion on charts, to be conducted by the Hydrographic Office.

The mean position of floating nav aids should be calculated from the observed ebb and flood positions, unless a position of the sinker/anchor can be deduced from the swathe bathymetry.

The position, characteristic, sectors and physical description of each fixed or floating nav aid should be compared against the published chart, the relevant List of Lights and Sailing Directions as a gross error check. It is important to verify that the derived positions for nav aids meet the required standards.

The final list of fixed and floating nav aids observed for and checked within the survey area should be compared with the original listing created from the published charts, List of Lights and Sailing Directions, in accordance with paragraph 4.8.3, to ensure complete coverage of all nav aids.

Any variations from the published data and confirmed with responsible authorities in accordance with paragraph 4.8.7 should be reported immediately by signal/e-mail to the Hydrographic Office and followed up with a Hydrographic Note.

The details of port radio operations obtained during the survey, in accordance with paragraph 4.8.8, should be checked against the relevant List of Radio Signals and Sailing Directions.

Details of any marine life, bioluminescence, secchi, deep scattering layer observations should be rendered. Details of other features, such as pock marks and brine lakes, and any sediment samples should be given with a description on how the observations were made.

If ocean fronts, eddies or internal waves have been investigated, details of their locations, the type of feature, the methods used and the sensors employed should be provided. Comment on how the data has been rendered and any conclusions made.

#### **6.5 Compliance with the Plan**

An assessment should be made of the completeness of the survey and its compliance with the Hydrographic Specification and the original plan. Any areas which require further investigation, including areas incompletely surveyed or the Hydrographic Specification requirements have not been achieved, should be identified and what actions are required to rectify the shortfalls, which may be due to equipment limitations or physical conditions. Any further work required should be highlighted and recommendations should be made on how it can be successfully approached in the future.

## 7. DATA RENDERING

### 7.1 The Report of Survey

When survey material of any sort is rendered to the Hydrographic Office, it must be accompanied by a report, in some form or other, of how it was obtained. In a few cases, such as Hydrographic Notes, this may be relatively brief, but in the vast majority of cases, the Report of Survey forms the core of the survey data, and should remark on every aspect of the survey and on all other data being rendered with it. For conventional bathymetric surveys, it is often divided into two parts; an example of their contents is contained at Appendix 2 to this chapter.

The Report of Survey is the principal means by which the Surveyor in charge approves the contents of ALL survey records and is thus a very important document, and the Surveyor must take considerable care in its presentation. It must give a clear and comprehensive account of how the survey was carried out, the results achieved, the difficulties encountered and the shortcomings. Emphasis within Part 1 should be placed on the analysis of achieved accuracies and whether the specifications called for in the survey specification and IHO Publication S-44 standards have been met. Part 2 contains the necessary technical discussion to support opinions expressed in Part 1. It should be borne in mind that it is often just as important to say what was not done and why, as to say what was done and how.

A thorough Report of Survey can reduce the need for subsequent correspondence between Hydrographic Office and survey unit, which otherwise may be necessary to elucidate points which have not been covered in a less exhaustive report. The example at Appendix 2 provides an outline of the material that it is felt advisable to include along with a format suitable for bathymetric surveys. It is useful to note against any paragraphs which are not applicable to a particular survey a brief statement of the form 'No ..... observations were conducted'.

The Report of Survey is as much a fair record of the survey as any other, and must be compiled and present with as much care, neatness and accuracy. The manner and format in which it is rendered to the Hydrographic Office will vary according to national requirements.

The Report of Survey and associated survey data will be rendered to the Hydrographic Office where it will undergo a rigorous validation and appraisal process. It is recommended that a complete copy of the rendered data should be kept in the survey unit until all queries have been answered. It should be remembered that the verified Report and data set will be archived and remain as the definitive data source for the creation of future products.

### 7.2 Data Requirement

The Hydrographic Specification will articulate the reason for the survey and the primary product requirement of the customer, ie safety of navigation or cable/pipeline route surveys will be bathymetry driven, minewarfare and archaeological surveys will be object detection led whilst environmental surveys may be seabed texture and water column based. The Hydrographic Office will detail what data is to be rendered on completion of the survey and to what time scale.

### 7.3 Data Format and Density

Most Hydrographic organisations have detailed standards for data format and data density to meet their requirements. The Hydrographic Specification will detail any variations to these standards in the data format, which will depend upon the survey system to be used and the systems available for verification and validation

of the rendered data. The modifications to the data density will be stipulated in the Hydrographic Specification.

Modern visualisation tools have allowed significantly greater flexibility to the surveyor in data presentation, both digitally and graphically. Care must be taken to ensure that the inherent cautiousness of hydrographic surveying is not blinded by the multi-coloured imagery which can be created with relative ease and minimal human interaction.

#### **7.4 Media Requirement**

The Hydrographic Specification will detail in which media the survey data is to be rendered and whether it is a fully digital survey or if fair graphics are required by the customer. The common media used are:

- a. DVD;
- b. CD-Rom;
- c. DAT Tape;
- d. Fair graphics on Ozatex/Cronaflex;
- e. Paper records.

Whatever the media, great care should be taken with the transmission and handling to ensure that the data arrives at its final destination uncorrupted and undamaged. Much of the data will be unique, will form the basis for amending and maintaining charts and publications until the area is resurveyed (probably very many years in the future), and will become part of the nation's archives as public records. It follows that this material must be afforded the highest degree of security at all times, for to lose a part or all of it would clearly be very expensive in time, effort and material.

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