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A COORDINATED APPROACH TO THE QUALITY CONTROL OF OFFSHORE POSITIONING

by D.N. McLINTOCK (*)

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ABSTRACT

This paper seeks to detail the principles and method by which a survey client can perform quality control on the positioning of a survey in an efficient and effective manner. In doing so it stresses the procedural aspects of the work rather than the technical, and does not give details of algorithms or computer systems used. The requirement for quality control and its general concepts are given and, using 2-dimensional geophysical surveys as a basis, the potential error sources and a detailed procedure to minimise their effect are described.

I. INTRODUCTION

In order to safeguard his own interests, it is necessary for the client of an offshore hydrographic or geophysical survey to perform strict quality control checks on the technical and operational aspects of that survey. This implies not only the real-time quality control on the acquisition vessel, it also involves both the pre- and post-survey procedures of the client and contractor. It is not restricted to one individual survey but must also include the assurance of the compatibility and usefulness of the data collected in the context of past and future surveys in that area.

(*) Shell Internationale Petroleum Mij.B.V., Dept. EP12/2, Postbus 162, 2501 An Den Haag, Netherlands.

This paper seeks to detail the principles by which to execute this control during all phases of a survey operation. It discusses a generalised overall process of obtaining and processing data, and highlights the areas in which errors can be, and often are, made. In doing so, it considers the process from the point of view of the client's own in-house procedures and his requirements of his in-field personnel. It is, nevertheless, equally relevant to the contractor.

As a basis for the discussions, the QC process required during a 2-dimensional deep seismic geophysical survey using a surface radio-positioning system is considered. Experience has repeatedly shown that this type of survey has a high frequency of positioning errors, examples of which are given. The same principles will also apply to other types of offshore survey and positioning, for example general engineering surveys and 3-dimensional seismic, which are discussed in section 7.

The need for quality control is discussed in Section 2, while the general concepts involved are given in Section 3. The pre-survey preparations discussed in Section 4 concentrate on the establishment and use of geodetic datums and control, the establishment of the navigation systems, and the importance to the client of an adequate knowledge of the contractor's systems and processes. In Section 5 the onboard client's representative's responsibilities during the survey are considered, with respect to both the real-time progress and effectiveness of the survey, and to his own and to the contractor's data collection and documentation. The final step in the process is the client's own in-house checking of the final results supplied by the contractor. This is presented in Section 6. The paper is concluded in Section 8.

2. WHY QUALITY CONTROL ?

QC is performed by the client to ensure for himself that a survey is performed accurately and correctly. By "accurately", it is implied that all specifications are met and the most efficient results are obtained from the collected data. By "correctly", it is implied that the survey is performed by a method which he regards as satisfactory, and which will provide a cost-effective product without unnecessary risks. This latter factor should not be used as a means of removing the initiative or responsibility from the contractor who may have more experience of, and be better qualified to do, the job. Nor should it necessarily be misconstrued as a sign of mistrust. It is normally both a means of ensuring that the different commercial interests of the client and contractor do not affect the survey process and product, and an insurance against possible errors and the effect they might have on the survey execution and interpretation, and on any subsequent operations.

Geophysical exploration surveys have been chosen as the basis for these discussions because they exhibit several of the more frequent causes of errors and constitute the greatest percentage of oil industry offshore positioning work. These problems stem from a number of factors.

(a) It is real-time dynamic process in the sense that the positioning system and computations alone provide the absolute position reference of the acquired geological data (this cannot be said, say, of a pipeline survey or installation

where the pipeline itself is a physical reference which can be re-surveyed). There is consequently no possibility of a re-survey of the positioning data alone.

(b) Valid geophysical data acquisition depends on correct positioning and navigation procedures and computations for gun firing, synchronous recording, and streamer tracking.

(c) The volume of data collected is very large and often spreads over a number of inter-related and inter-dependent systems (not only navigation but also geophysical).

(d) It is often difficult for the QC representative to access data independently of the contractor's systems and, in many cases, this cannot be done at all.

(e) It is regrettable that among the seismic contractors there is a great lack of professional topographical survey organisation and of qualified surveyors.

To quantitively illustrate the problems which are often encountered, Table 1 summarises the positioning errors found in surveys checked by Shell International in The Hague during the period from July 1982 to December 1983. This total of 9.7 % of data in error is clearly not tolerable for what is, in the vast majority of cases, a basically simple computational process. Several different types of errors were found including incorrect smoothing, computations on the wrong spheroid, incorrect datum conversions, and wrong base station coordinates.

This figure is even more alarming viewed in the context of the method of QC employed and the volume of data tested. "Checking" involved comparing the

TABLE 1

Survey area	*Year*	*km surveyed*	*km in error*
N. Africa	1981	1 949	445 (a)
W. Europe	1981	347	—
W. Europe	1981	2 682	—
E. Africa	1982	1 671	2 (b)
W. Europe	1982	320	—
W. Europe	1982	896	—
W. Europe	1982	548	—
W. Europe	1983	227	—
Middle East	1983	1 648	412 (c)
N. Africa	1983	553	195 (d)
	Σ	10 841	1 054

% error = 9.72 %.

Notes :

(1) All surveys used Syledis or Maxiran.
(2) Only errors greater than 30 metres lasting for more than 0.5 km are given.
(3) No North Sea data are included.

Reasons :

(a) Computations performed on wrong spheroid, wrong station coordinates used.
(b) Incorrect smoothing, filtering, or prediction.
(c) Wrong base station coordinates used (70 km still wrong after second attempt).
(d) Invalid datum transformation.

in-house processed (contractor supplied) raw data, with the contractor processed coordinate data. This method of QC was clearly far from ideal as it used several important parameters provided by the contractor. Errors made in post-processing might consequently not have been detected, and the possibility of detecting errors made onboard then duplicated later will have been much reduced. It also depends totally on the fundamental question of whether the supplied "raw" data is in fact "raw". A further major concern is that this data set represents only about a quarter of the marine data handled in The Hague office during this period. The majority is provided in coordinate or map form, without accompanying raw data, and it therefore remains unchecked.

All the data errors shown have been detected at the client's post-processing stage rather than in real-time onboard the vessel. This implies that they have been made during, though are not necessarily caused by, the contractor's post-processing. In short, without the client's QC post-processing, they would probably have remained undetected. Not included in this table are those errors discovered and corrected prior to, or during, the survey (e.g. wrong input of C—O values or pre-plot lines, incorrect system calibration, etc.). These are not presented as they are difficult to quantify, one of the real-time QC objectives being to spot potential error sources and to prevent their occurrence. Inaccurate documentation, data collection, and computation in the field is likely to be assumed correct at a later date in post-processing, and it is therefore much more effective to isolate and correct problems in real-time as they occur. A necessary part of this real-time QC is to obtain independent data in order that the post-processing QC does not have to rely on data supplied by the contractor.

3. BASIC CONCEPTS

The QC process can be nominally split into three separate tasks : the pre-survey preparations, the data acquisition phase onboard the vessel, and the post-survey processing. The first two are very closely related both in time and location, whereas there is usually little direct link between these and the later post-processing stage. It is the quality of this necessary communication between phases which is frequently shown to be a major source of error. This increases the importance of continuity in QC throughout the whole survey process.

Each survey will require its own quality control procedures for maximum effectiveness according to its objective, area, type, contractor, and the systems being used. There are, however, two general criteria to be met in establishing these procedures.

(a) The client should seek to maximise his cost-effectiveness by not fully duplicating the contractor's work, but by just gathering sufficient data as necessary to be able to validate the final survey results.

(b) As much data and as many survey parameters as possible must be acquired independently of the contractor. That data not able to be acquired independently should be checked for validity in some way (e.g. if the QC system is not interfaced to the navigation receiver and shot triggering

signal, then the data taken from the contractor's print-out must be verified as being "raw" data, recorded precisely at the shotpoint).

The former definition allows a broad interpretation. The most effective method of onboard and post-processing QC would undoubtedly be a fully interfaced computer system with 24 hour per day manning, thus eliminating any dependence on the raw data supplied later by the contractor. This may be classed as cost-effective in some circumstances, but it will be assumed here that QC is performed using, at most, a small portable desktop computer (e.g. an HP85). Emphasis will consequently be given to procedural considerations.

Within the technical aspect of QC, there are two basic concepts which are consistent throughout, namely the time scale and the possibilities of recovering errors made. With regard to time, the process can be divided into :

(a) Short-term QC :
that part relevant to the execution of one individual survey (e.g. the real-time onboard QC or the pre-survey calibrations).

(b) Long-term QC :
that part relevant to the compatibility of an individual survey with other surveys undertaken before and after it (e.g. the geodetic datum used or, again, the pre-survey calibrations).

With regard to the potential errors, these can be categorised into :

(a) Recoverable :
those which, even when made, can be corrected before final presentation of the survey results if detected (e.g. a post-processing error after correct data collection on the vessel).

(b) Irrecoverable :
those which, if not noticed when made, will either never be noticed or be non-correctable (e.g. wrong input of C-O values into a navigation receiver or incorrect offset measurements).

In both categories there are obviously cases which fall into either of the possibilities, but this initial breakdown allows an assessment to be made of the most important areas.

In performing QC onboard the vessel it is necessary to compare position fixes computed by the contractor and by the QC. The main purpose of this is to identify both possible errors in the computations and modelling, and in the navigation systems themselves. It is consequently not necessary that the QC compute a "correct" absolute vessel position. The important consideration is that the computations are independent of the contractor, are easily interpretable, and will highlight potential problems. Any such evidence should then lead to a much closer look at the raw data. In order to achieve this objective it is necessary that the QC system compute both a raw and a filtered position (from its own model).

Before proceeding to discuss details of the QC procedures, it is useful in this section to make some general comments affecting the outlook and definition of a QC process.

(a) Incorrect positioning of a survey line may not just result in the incorrect positioning of a geological structure. It may cause an incorrect interpretation of the nature and shape of that structure.

(b) The synchronisation of positioning and geophysical data acquisition is most critical. However, as a major function of the navigation system is to trigger the firing of the seismic source, it is regarded here that the geophysical acquisition systems are slaved to the navigation. This synchronisation problem will consequently not be considered further, as it is a geophysical rather than a survey QC task. This should not be confused with the required synchronisation of the navigation systems in time, shotpoint counting, and recording.

(c) QC reporting methods should ideally be location independent. However, in practice, large geographic separation and hence poorer contact between both contractor and client departments and representatives are a major problem. This is made worse when the positioning QC is performed outside the topographical survey function, e.g. by the geophysical representative, which will almost inevitably lead to a lower quality QC product due to the time available, his probably lower positioning knowledge, and the reduced coordination of the different aspects of the positioning QC. The procedures and guidelines must consequently be specifically designed to minimise the effect of these three factors.

(d) It is always more efficient and reliable to perform a maximum amount of QC on the vessel and to present this in the most convenient format to the client's post-processing office, for example using standard forms. This latter factor is made much easier and effective if the representative has some working knowledge of the client's procedures. To take a very simple example, if the client's data base stores survey lines in alphabetic rather than surveyed order, a large amount of time can be saved by presenting all reports in the same way. Contractor's reports should be structured by similar principles.

(e) It is absolutely necessary to incorporate positioning and navigation specifications in a contract. This is very often overlooked or undervalued in many engineering and geophysical projects where the positioning constitutes only a small fraction of the total budget.

(f) The two objectives of positioning are accuracy and repeatability. Although the latter is very important for re-positioning, it is of only short-term value and should not be accepted as a substitute for attaining maximum possible accuracies. The rapid development in radio positioning systems and the logistic and contractual problems involved in re-establishing a navigation chain make accuracy the definitive requirement in most cases.

(g) A distinction must be made between the navigation and positioning tolerances. The former are the bounds within which the vessel must be steered, whereas the latter is the accuracy with which the actual position of the vessel must be finally known.

4. PRE-SURVEY PREPARATIONS

The pre-survey preparations establish both the "basic data" for the survey and the working systems and procedures for use on the vessel. Initial scouting of the area and the logistic support requirements are not discussed here. Broadly speaking, the former involves the definition of the geodetic datum, coordination of shore stations, and the gathering of general survey data on the area. The latter involves the calibration and establishing of the radio positioning system(s), and the establishing of ship-to-shore communication procedures.

The amount of QC involvement at this phase is highly variable. However, the result of it should be that the QC representative is :

(a) briefed and equipped so that he can perform his "routine" job on the vessel.

(b) fully aware of the onshore organisation and preparations.

With regard to the latter, sufficient confidence should exist in the preparations to be able to consider these as a less probable error source in the event of positioning problems on the vessel. This is important for three reasons. Firstly, it is extremely difficult to solve shore-based problems from the vessel, due to the often difficult communications and slow response times of the shore team. Secondly, the logistic difficulties of, say, a re-calibration are very large and would cause costly navigation downtime, quite frequently charged to the client. Thirdly, if shore problems are detected, then the representative must be able to effectively appraise remedial action designed to minimise downtime. This requires a working knowledge of the shore organisation.

Presented below is breakdown of all the items which ought to be checked and with which the representative ought to be familiar. Comments on individual items will be restricted to those which are either not self-explanatory, or which deserve a comment or opinion.

(a) *Establishing the geodetic datum* either by use of an existing datum or by defining a new one, probably using the Transit satellite system. It is generally preferable for legal reasons to use the datum in which the concessions are defined. Although local triangulation stations may also be defined in this datum, Transit observations are highly desirable to verify the local network and to establish datum shift parameters. These can then be used to relate both data acquired on different datums, and data acquired using Transit as a navigation system.

(b) *Defining the projection system.* For convenience, the same system should be used in real-time as will be used for final data storage. Direct checks can then easily and effectively be made after the survey with data recorded onboard.

(c) *Determination of sites of base stations* to give adequate 3-way fix coverage throughout the survey area.

(d) *Coordination of shore stations.*

(e) *Calibration of radio navigation systems in the field* to determine zero and scale errors by long and short baseline observations (ref. [1]).

(f) *Calibration of the vessel gyro and repeaters* at the dockside. This is frequently impractical but they should have been recently checked.

(g) *Setting up of base stations* involving use of correct geodetic point, orientation of antenna, use of identical beacon/cable/antenna/combination as for calibration, and no added input of fixed delays at beacons. It

must also be ensured that the latter is never done without authority from the vessel.

(h) Verifying the contractual and operational relationships between the main contractor and the navigation sub-contractor, if any.

(i) Verifying the ship-to-shore communication procedures such that no unnecessary downtime occurs in the event of system failure, and so that the status of beacon movements is always known. This is especially a problem when the navigation systems are supplied and maintained independently of the seismic contractor.

(j) Familiarising with the contract specifications and conditions.

(k) Familiarising with the contractor's systems and procedures both onboard and in post-processing. This will have to be done both through the vessel and through his post-processing centre, the latter probably being via the client.

(l) Gathering other information required for the survey (e.g. bathymetry, well positions, nautical charts), and familiarising with the other information required from it.

(m) Making all necessary arrangements for the installation of the QC computer and becoming familiar with its use.

(n) Instructing the shore team on the final reporting requirements. This should include chain and beacon downtime and reasons thereof, changes and adjustments made including beacon moves, repairs and replacements, and any malfunctioning of equipment. This report should be based solely on time rather than on the survey progress.

(o) Instructing the vessel navigators on the final reporting requirements which should include the items in n) above (logged independently, not copied), plus a line log giving patterns used, C-O's applied, average fix quality, and line statistics. It should also include offset diagrams, a summary listing of problems encountered, and a daily log.

(p) Ensuring that all navigation equipment and spares are onboard and in working order.

The output of this phase from the QC representative to the client and to the vessel should be :

(a) full descriptions of the shore stations used containing the geodetic and height datum information, projection system, coordinates and heights (of ground station and beacon), station and access diagrams, landowners with addresses, and beacon installations;

(b) calibration report, giving a summary of final results, the baselines used, all raw data acquired, what adjustments have been made to the equipment (e.g. zero delays input to beacons), and what action is planned (e.g. how zero/scale errors are to be applied).

This report will ensure that the post-processing phase has all the basic geodetic and navigation chain information independently of the contractor and the vessel. This is designed to avoid the compounding and duplication of errors made during the actual survey.

5. DATA ACQUISITION PHASE

The main function of onboard QC is to assure in real-time that the navigation, positioning, and gun-firing are within the specified tolerances, and that the logging of data is correct.

This definition is deliberately broad and will be detailed further later in this section. Before this, an example of the minimum QC that might typically be done is briefly described below in order to highlight potential problem areas.

The positioning is usually spot checked off-line using data acquired directly from the receiver display/printer or from the contractor's print-out. Less often, but preferably, it is checked on-line using an interface directly to the navigation receiver and shot trigger. In this case, it is also possible to assess total line statistics independently (i.e. shot point interval, distance offline, and fix quality), otherwise it either cannot be done or the contractor's system has to be used. The manual logging of data should be relatively easy to verify but the checking of the digitally recorded data is normally a problem, due to the limited time and facilities for "read-after-write" dumps, the several systems used, and their relationships and synchronisation.

Some major drawbacks of this process are :

- these procedures do not ensure that the data sent from the vessel is correct or that it comprises all data required by the contractor for both his own post-processing and for supply to the client;
- navigation data is often recorded on several different systems; it is not necessarily the one used in real-time that will be used for post-processing;
- it is frequently found that the navigators are unfamiliar with the post-processing procedures. They therefore are likely to be unaware of precisely what data is required and which secondary data can be used in post-processing. This may result in them mis-advising their post-processing office;
- data prediction and filtering can be badly applied (usually too strong a filter is used, thus straightening the lines and "delaying" vessel movements). This can be very difficult to detect without an interfaced QC system;
- it is often difficult for the representative to access raw data to perform checks. Data print-outs are often not raw but smoothed and/or corrected data;
- even if the QC computer is interfaced to the navigation receiver, only limited value can be obtained without interface to the shot triggering and numbering signals;
- line statistics are required to assess adherence to specifications, but this requires either a fully interfaced QC system or a reliable contractor QC system. Without one it is generally impractical to perform these tests for every line, and it would in any case be a weak point from which to request a reshoot;

— synchronisation of all navigation systems in counting, time, and recording is impossible to check without access to the digital recording systems;
— insufficient attention is paid to secondary parameters which can be extremely useful for detecting positioning errors and for planning future surveys, e.g. satellite positioning, water depth.

With the aim of, firstly, identifying and then either correcting or at least noting areas of dubious positioning quality, and secondly, ensuring that the later post-processing stages of both contractor and client are provided with all necessary information, a breakdown of the QC tasks onboard the vessel designed to minimise error probability and effects should be :

(a) *Check navigation system calibrations* by baseline crossings/extensions. This should be done by fully plotting the observations either side of the baseline, not by just taking the minimum sum of ranges which is noise dependent.

(b) *Recalibrate system units after repair or replacement* either onshore or offshore, but with a full calibration when logistically possible.

(c) *Calibrate other systems used* at start-up and at intervals throughout the survey, e.g. echo sounder, gyro, doppler sonar.

(d) *Check offset measurements* to the survey reference point from the navigation antenna, other vessel sensors, the seismic source, and the first common depth point. At a later date the data may be reprocessed using a different reference and therefore all the relative measurements must be in the final QC report.

(e) *Verify the validity of QC fix checking* by, firstly, checking that the contractor's prints-outs are raw data, and secondly, checking the reception of navigation and triggering data if the QC computer is interfaced. Both of these can be done by setting the heaviest possible filter on the contractor's navigation computer and then either sharply manœuvering the vessel or switching off one of the received patterns.

(f) *Check the input to the contractor's navigation computer* for each line to be shot for both primary and secondary system, i.e. preplot line coordinates, station coordinates, zero and scale errors in both the computers and receivers, datum/projection, offsets to reference points, and smoothing and filtering criteria.

(g) *Check the contractor's manual logging* and, where possible, the digital logging.

(h) *Compute 3-way fixes* from raw data at least every 50th shotpoint and more frequently during instabilities and station changes. When the QC is interfaced to the navigation receiver, then these computations should be both raw and filtered, as discussed in Section 3. The forms on which these data are logged for inclusion in the final report should also include space for the time, computed coordinates, noise levels, residuals, and comparisons with the contractor's computations and secondary systems.

(i) *Continuously compare the secondary navigation system with the primary* in order to detect errors and to know its accuracy and offset in case of failure of the primary (hence the requirement for calibrating doppler sonar and gyro). Every opportunity should be taken to check all data for lane slips or range anomalies, and regular reverse computations should be made to ensure that the theoretical navigation system readings at a desired location are similar to those being displayed and used.

(j) *Check the adherence to the tolerances* for navigation, shotpoint interval, and position fix quality.

(k) *Keep a QC log* giving the downtime and reasons thereof, changes in the navigation system, equipment repairs, adjustments/replacement, malfunctioning of equipment, base station moves, and pattern delay changes.

(l) *After the survey* a full post-calibration of the radio positioning systems should be performed as detailed in Section 4.

The output of this phase from the representative to the client's post-processing should be a report containing :

(a) Basic survey data comprising datum and projection, positioning system chain data (including equipment serial numbers) and calibration summary.

(b) Separate lists of the items given in l) above.

(c) A list, preferably digital, of the raw data used in h) above.

(d) A separate list of raw data during particularly bad periods of positioning system instability; the times of these should also be given.

(e) A list of all pattern changes and failures.

(f) The results of the baseline crossings/extensions including a comparison with the shore calibrations.

(g) The results of any comparisons made with "known" points, e.g. fixed platforms.

(h) A separate report of the QC daily log.

(i) A report from the shore team of all station moves, failures, adjustments, and downtime, plus their daily log.

Items *d)* and *e),* and to a lesser extent *c),* will be used to ensure that the data provided by the contractor on the final raw data tape are in fact "raw". Items *a)* and *e)* are required to aid the validity of, and to facilitate, the client's post-processing.

This report, as for those from the pre- and post-survey phases, should be both part of a total survey QC report and a stand alone document.

Together with the pre-survey QC report, the client's post-processing office should have all the data for a recomputation of the survey, except the raw range/pattern readings. These are provided by the contractor but can be verified to a large extent.

6. POST-PROCESSING PROCEDURES

The contractor will use the data received from the vessel and either accept the coordinate data or, more commonly, recompute it. From this he will generally supply to the client an "exchange" ("post-plot") data tape which has records comprising line name, shotpoint number, and grid and geographical coordinates, together with post-plots of this data at the required scales. These should agree, as they should be produced from the same data. The contractor should also supply a "raw" data tape and all relevant information for a full survey recomputation. This tape comprises line name, shotpoint, date/time, water depth, gyro and observed raw (not corrected, smoothed, or filtered) ranges/pattern values.

Some problems often encountered are :

- the contractor is almost totally reliant on the data package received from the vessel;
- real-time QC of the post-processing in the contractor's office is generally impractical and, therefore, errors made there will appear in the final coordinate data;
- the data arriving from the vessel should include raw data which can be almost immediately transcribed onto a tape for the client. However, if for some reason either raw data is not recorded, or the wrong data is transcribed, then the client's post-processing QC can be almost totally invalidated;
- in many cases, the contractor does not supply a raw data tape, in which case no checks can be made.

The procedures detailed below should be followed to verify the final coordinate data supplied. The QC reports from the vessel and from the pre-survey phase should be used as they are essential for coordinating the two phases effectively. Without them, there is a great danger of overlooking or duplicating errors.

(a) Check that the data on the raw data tape is "raw" using items *c), d)* and *e)* of the onboard QC report.

(b) Check the survey data in the contractor's report with the onboard QC report.

(c) Compute the survey using the raw pattern data from the contractor and all other parameters from the QC report. In the application of offsets, the course-made-good should be used rather than the gyro reading obtained from the raw data tape.

(d) Check the "exchange" data and the final maps by comparison with the data from *c)* above. The maps may not necessarily have been produced from the exchange tape and, therefore, they must both be checked.

(e) Check the seismic sections for use of the same reference point as used for the final positioning and mapping (i.e. antenna, source, or first common depth point).

(f) Check the seismic sections for correct computation and annotation of line intersections, both for this survey and older data.

(g) Inform the contractor of any errors so that his database is also corrected. If this data is then exchanged, the correct positioning data will be available.

The result of this phase should theoretically be a correctly positioned geophysical survey. However, the process does not stop here. The maintenance by the client of a seismic positioning data base designed to satisfy mapping and coordinate requests will also require quality control. Compatibility of different surveys will have to be ensured and advice on relative accuracies and reliabilities given. Added to this, as the annotation of seismic sections is partly a positioning problem, any reprocessing of seismic data should also have a topographical involvement.

7. DISCUSSION - OTHER SURVEYS

The preceding sections have gone into the details of how and why a 2-dimensional seismic survey should be quality controlled. The quality controlling of other types of positioning survey, such as engineering and seabed inspection surveys, follows basically the same principles. Modifications will be required to some procedural details according to the required end-product, the long-term interest of the work, the equipment used and the contractor's survey organisation, but the concepts as described in Section 3 will remain the same. For example, the positioning of a production platform is almost entirely a real-time process with no post-processing being required unless errors are made during the installation. In this case, positioning repeatability may be as important as accuracy in locating the platform relative to other structures, such as already laid pipelines. The contractor's survey organisation is a very important factor, there being generally a large difference between the specialist topographical or hydrographic survey contractor and the navigation/positioning department of an engineering or geophysical company.

The most important differences, however, are caused by the positioning equipment used. For most surface positioning using radio navigation systems, the procedures are as described, with due allowance being made for the particular system and its operating frequencies, range, stability and measurement principle. The use of underwater acoustic systems and satellite navigation, either by Transit or GPS, gives special problems. Both present greater difficulties in independently accessing raw data and require greater complexity in the QC software to be used, plus more access to the hardware. In order to perform fully effective QC, these facilities must be available, but one then runs the risk of unnecessarily duplicating the contractor's system. With the advent of GPS, it will be interesting to see the reaction of the industry to this problem. It will no longer be possible to take the attitude that satellite navigation is only accurate to a few hundred metres and, therefore, is not worth quality controlling.

3-dimensional seismic surveying is becoming increasingly important and is now regularly used. The QC of the positioning and navigation of the vessel in real-time should proceed as before, but the two main extra requirements of determining the shape of the streamer and of binning the acquired traces present much more complex problems. It is impractical to do the latter without a QC computer system fully interfaced to all the vessel and streamer positioning systems, e.g. surface and acoustic positioning, gyro, cable compasses, lead-in angle sensors and shot trigger. Similarly, only procedural checks and coarse computational checks can be made for the former without such a system.

To partly overcome this problem it is necessary to return to the original concepts. Streamer positioning data is almost always post-processed to improve accuracy using methods such as spline fitting, dynamically calibrating the changing fixed errors of the compasses (if they, in fact, do change), and by applying hydrodynamic models for the cable. Therefore, the streamer positioning is "recoverable" providing the vessel calibrations were satisfactory and all necessary data has been transmitted to the post-processing centre. It can, therefore, be quality assured by the client's post-processing in the same way that surface positioning is by using the raw data supplied by the contractor, which is verified by the data from the onboard representative's report.

The problem of binning the data is more critical, as this is partly an "irrecoverable" error source. Incorrect binning may lead to gaps in the survey coverage not discovered until afterwards. The only solution to this is a fully interfaced QC system duplicating that of the contractor. Anything less may indicate coverage gaps but the data would be highly subjective and a very poor basis on which to negotiate with the contractor for extra lines to be shot, especially if his system shows adequate coverage. In view of the many problems experienced in 2D work, it is very important to have a highly experienced survey representative on board during a 3D survey, due to the larger amount of work required and the increased complexity of the systems used.

8. CONCLUSIONS

It has been attempted to show the importance of a well-organised quality control process and to provide a general procedure guide while avoiding too many specific details. In doing so, all aspects have been considered, but it is acknowledged that the execution of some of the items discussed may have to be dropped for some surveys, due to time and access constraints. Each individual survey and contractor/client pair will require these procedures to be tailored accordingly.

A description has been given of :

(a) Why quality control is required, and the basic concepts of its application.

(b) Several of the error sources which are frequently encountered.

(c) A method for the quality control of navigation and positioning throughout the survey process.

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