IHO SP 44 Standards for Hydrographic Surveys and the demands of the new century.

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Keeping any standard up to date is a never-ending task. For example, rapid advances in multibeam technology and increasing interest in deeper areas of the ocean driven by UNCLOS mean that IHO SP 44, Standards for Hydrographic Surveys, 4th Edition, needs to be reviewed and expanded. SP44 provides 4 different requirements for vertical accuracy, successively degrading from the critical to navigation inshore region to the offshore deep regime. Requiring lower standards in deeper water has some justification for navigational charting, yet ignores the needs of a wide spectrum of other ocean users, and ignores the standard that MBES are capable of achieving. Article 76 of UNCLOS, for example, requires the accurate location of the 2500m contour, a location which the current version of SP44 allows hundreds of meters to kilometres of horizontal uncertainty. Furthermore, the ability of swath bathymetric sonars to achieve vertical accuracy actually increases with depth. For these reasons, it is proposed that SP44 be revised or expanded to include those cases where accuracies similar to those in shallow water are required well below navigation depths

Introduction

Establishing standards in any field is never easy. Establishing standards that must be agreed to by 70 nations is difficult. Establishing standards in a field that is undergoing rapid technological transformation is a constant game of catch-up. Doing all these while establishing standards for measuring something that can not be seen and in which the measurement that the standard is to be applied to in fact generates the standard is - hydrography.

The International Hydrographic Organization (IHO) has issued standards for the accuracy of echo sounding since 19xx. (2^{nd} edition 1982, 3^{rd} 1987, 4^{th} 1998) under the identifier SP44 or, more recently, S44. The preface to the 3^{rd} edition tacitly recognizes the rapidity of change with a brief statement that SP 44 will be updated every five years, a worthy goal that has proven impossible to achieve. It is very instructional to compare the 3^{rd} and 4^{th} edition, and try to provide guidance on how the 5^{th} edition can be improved.

Although the standard was produced by the IHO for use by hydrographic surveys in support of navigation, since it is the only International standard for survey accuracy and carries the imprimatur of a highly respected International body, it is referred to or cited by a number of users who are not concerned with navigation.

Description of the standard

The third edition is entitled “IHO Standards for Hydrographic Surveys, Classification Criteria for Deep Sea Soundings and Procedures for Elimination of Doubtful Data”, treating these as three separate subjects. The fourth edition spends one page on doubtful data and combines the first two, hydrography and deep sea sounding into one table. The combination of two quite different requirements is not necessarily an improvement and should be examined more closely. In its Preface, the 4th edition states that it is an attempt to broaden its outlook to meet the needs of "a much more diverse group than previously recognized. Hydrographic data is also important for Coastal Zone Management, environmental modeling, resource development, legal and jurisdictional issues, ocean and meteorological modeling, and engineering and construction planning, and many other uses." Most would agree with this as reflecting the actual conditions in most offshore areas. However, the Introduction on the next page seemingly contradicts this by stating that the 4th edition specifies " different accuracy requirements for different areas according to their importance for the safety of navigation". We examine this further below under "bias".

Rather than dividing areas to be surveyed into the 3rd edition's two zones of less than 200m depth and greater than 200m depth, the 4th edition provides for 4 zones:

> Special Order - "specific critical areas with minimum underkeel clearance and where bottom characteristics are potentially hazardous to vessels" (generally less than 40m)
>
> Order 1 - "harbours, harbour approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density" (less than 100m)
>
> Order 2 - "areas with depths less than 200m not covered by Special Order and Order 1 "
>
> Order 3 - "areas not covered by Special Order, and Orders 1 and 2 and in water depths in excess of 200m".

For each of these it specifies Horizontal Accuracy, Depth Accuracy, 100% Bottom Search, System Detection Capability and Maximum Line Spacing. It does not address how these are to be combined. (include Table 1 from SP44, 4edition)

In this paper we focus on the issue of depth accuracy, leaving an examination of bottom search for another report (jhc in progress).

Bias

All measurements are subject to bias, some controllable, some a function of the equipment in use at the time. Standards can seek to eliminate these biases or to enshrine them, and the wise users of standards seek to understand which of these alternatives have been followed. The controllable safety-of-navigation bias is expressed as shoal-biasing every uncertainty source for safety's sake, but that does not necessarily serve the best interests of the non-navigational users of hydrographic data specified in the introduction to edition 4. An example of equipment-dependant bias could be the in older-generation radiopositioning systems, in which measuring the risetime on a noisy, stretched-out pulse will always result in a too-long distance measurement, presumably placing all depths it measured further from the control point.

Not all uncertainties are biased, of course. For example, errors caused by beamwidth or sound speed error effects are as likely to occur one way as the other.

The standard does not address the issue of bias. Presumably, it is left to the hydrographer to work around the biases and still meet the requirements of the standard.

*SP44 standards are "*a priori*" depth error requirements*

The standards define the accuracy that the various elements of a survey are required to meet. They offer no instruction as to how one would assess whether these requirements have been met, nor what to do if a survey falls short in one category or in all of them.

Conventionally, there are two general approaches to error estimation, *a priori* and *a posteriori.* Before a survey is conducted, an application of the *a priori* approach tries to assess how well each piece of data could be collected, based on a theoretical appreciation of the equipment and methods used, the geometry and geomorphology of the area, the physical characteristics of the water mass, and other practical considerations. After conducting such an analysis, it might be concluded that the proposed survey would not meet the standard, leading to a change in the plan, and a reassessment to determine wither the new plan would meet the requirements of the standard. It might also be determined that the proposed survey could exceed the requirements if conducted as planned, possibility leading to a modification of the survey. Used this way, SP 44 provides a useful measure against which planned surveys can be compared.

Once results are in, the *a posteriori* approach to error estimation attempts to determine what accuracy really was achieved. The data are examined and tested resulting in an indication of how well they behave. How closely the real data will approach or exceed the standard will depend the detection and elimination of blunders and systematic biases and short lived anomalies in the water (unusually high water level, for example) on the factors included in the *a priori* approach plus some new factors introduced by the real world. The biggest of these is the slope and roughness of the bottom. Achieving agreement between checklines is extremely difficult over flat seafloors, and over extremely rough seafloors. Of course, in a previously un-surveyed area, these can be extremely difficult or impossible to predict, and that may be reason enough to not try to include them in an *a prioiri* error estimation. However, once a survey has been conducted, they can strongly influence the results, and there should be a feed-back loop that would incorporate the slopes detected. It is possible that two surveys, identical in all respects except the roughness of the seafloor beneath them, would be classified into different orders. SP44 Edition 4 does not instruct that any assessment be carried out. (Edition 3 did so to some extent, through the requirement to run checklines and to examine the results where checklines disagreed by more than twice the accuracy requirement (.3m to 30 m. 1% deeper than 30).) However, can it be claimed that a survey "met" the standard if no post survey check was carried out to verify that it did? It could of course be claimed that surveys were planned to meet the standard, but planning and realization are not always the same thing.

This begs the question of what happens if a post-survey analysis reveals that the survey has not achieved the planned standard. Can the survey be rated at a lower order? Can parts of a survey be rated at one order, other parts at another order?

Application to measurements

Standards are something to which real measurements are compared. Preparing standards for hydrographic data accuracy is complicated by the fact that each sounding represents the sum of several measurements, each containing errors. How these interact and accumulate is critical, yet not always solvable. How to determine whether a sounding in the middle of a bay is within some specified accuracy is close to impossible. SP44 has taken the approach of separating the measurements that make up a sounding and classifying them individually. While this does produce a standard, it leaves many questions unanswered when trying to evaluate real-world results. Does one component have precedence over another, or does a survey fail to meet standards if it does not meet the criteria in one component or in all of them?

Measurement theory indicates and good survey practice demands that surveyors attempt to minimize errors by

a) repeating each measurement several times with the expectation that errors will cancel one another (sometimes we even discard maximum and minimum measurements completely) and
b) designing the sequence of the series of measurements in such a way that some measurements can be compared to other measurements taken at a different time in the sequence (for example, leveling circuits must close).

In hydrographic surveying, these principles are followed when establishing vertical control and position fixing; sounding, of course, presents particular logistic problems which militate against rigorously applying the above principles. To repeat each sounding, even once would reduce speed to a small fraction and magnify cost exorbitantly, a totally unacceptable state of affairs considering the size of the task confronting us. However, condition b) can be satisfied to some extent by running check lines approximately perpendicular to the main survey lines. At the intersection of two checklines, the hydrographer was attempting to repeat both depth and position measurements. That is, it was thought that the vessel was at the same location as previously, and were that true, the water depths observed should be the same. Edition 3 of SP 44 recognizes this and states that intersections at which the difference in depth exceeds twice the specifications should be investigated. Edition 4 states only that crosslines should be run, but gives no instruction on how to use them.

A closer look

Balance in importance between fixed and variable errors

SP 44 correctly divides errors into two contributing types, fixed and variable. Constant errors are those that have the same value no matter the water depth, while variable (depth-dependent) errors are a fixed percentage of water depth and thus grow larger (vary) with deepening water. Each type of error is summed with other errors of the same type. The two types are the combined as RSS, that is the square root of ((Fixed errors) squared + (variable error multiplied by depth) squared). RSS is a very powerful tool, with a few important characteristics. One is the way the relative sizes of the numbers being summed interact with one another. When they are similar, they each have an effect, but when one is significantly larger than the other, the larger one dominates to the extent that the contribution of the smaller diminishes to the point of being negligible. This captures the real world, and should be carefully allowed for in any standard.

It is interesting to examine these numbers as currently expressed in Edition 4, and to compare them with Edition 3. The third edition specified that for depths less than 30m, the error could be 0.3m, and for deeper depths it could not exceed 1 % of depth. The 4th Edition's Special Order, the fixed error of 0.25m is dominant to a depth of about 34m. At 40 m, which is the max depth for Special Order, total error = .39m, slightly more stringent than edition 3. . Moving to deeper water and relaxing the standard, for Order 1 the fixed error of 0.5m is dominant to a depth of c38m, at which point it and the variable error make the same contribution to the total. At 100m, the max depth for Order 2, the total error = 1.4m, not as tight as the 1m demanded by the 3rd edition.. The remaining orders, 2 and 3, share the same errors, a fixed error of 1m and a variable error of .023 x water depth. At about a depth of c43m fixed and variable make equal contributions, but after that the variable error quickly comes to the fore. At 200m, the max depth for Order 3, the total error is 4.7m while at 2500m, the depth important for UNCLOS, error is 57.5 m, to which the fixed error contributes a mere 8mm! Errors allowed in these zones are more than twice (2.3) those that were allowed under edition 3.

Much more interesting in this table is the observation that required accuracy actually increases with increasing water depth. This seems to contradict the overall intent of sp44 Table 1, wherein Horizontal Accuracy, Depth Accuracy, 100% Bottom Search, System Detection Capability and Maximum Line Spacing are all arranged to lessen the accuracy required as the bottom becomes less likely to interfere with navigation.

Depth Accuracy as expressed in Table 1 must be applied with care. Although the Table lists values for fixed and variable accuracies, they must be combined and the result is the depth accuracy. It would seem logical that where one is so small in relation to the other that its effect is negligible, that the smaller one be allowed to exceed the values in the Table. Otherwise, a data set could be failed for missing the fixed error target by a few mm, yet that miss would be totally meaningless in terms of overall accuracy.

Beam width errors

Sound energy emitted from an echosounder transducer face spreads as it travels through the water column, and this spreading effects the manner in which the returning signal describes the seafloor. These effects included the introduction of horizontal displacement when the seafloor is sloping, the smoothing of the shape of large features and the obscuring of features whose wavelengths are less than twice the ensonified area. Great efforts on the part of sonar engineers have produced transducers and arrays that control this spreading and allow the focussing of the sound energy. In fact, the history of sonar development is one of continual progress towards finer and finer resolution. Cone widths of 2 or 3 degrees, as used in MBES, resolve a great many of the issues that plagued deep sea sounding in the era when cone widths were a order of magnitude greater. Perhaps because of this progress, and because it does claim to be a standard for future data collection, SP44 make no mention of cone effect.

Unfortunately, not all surveys in the immediate future will be MBES based, and sounders with wide cone widths will continue to be used for some time to come. It is instructive to examine the limitations indirectly imposed on beam angle by the specifications. Table x shows that, if the fixed error is taken as the maximum for each order, and that error due to beam spreading is considered to be the only source of variable error, then for Special Order, the maximum allowed beam angle is 14 degrees, for Order 1, 10 degrees, and for Orders 2 and 3, the maximum allowed beam angle is 24.6 degrees. Survey plans must consequently incorporate sounders with appropriate beam widths.

Sampling along Tracks or Lines

Edition 4 includes “Maximum Line Spacing” as a category to be applied in the standard. Special Order is excluded since 100% bottom search is compulsory, presumably meaning that the line spacing will be dictated by the characteristics of the sonar system used. For the numbered Orders, line spacing is given as function of depth. (The old hobgoblin yet again) However, it says nothing about the number of soundings required along track. Soundings could be spaced to match the line spacing, spaced at some arbitrary distance possibly related to sizes of figure at plotting scale, or spaced to capture the bottom profile. The latter would include:

a) Preservation of small features;
b) Preservation of significant corner angles
c) Preservation of any included frequencies;
d) Preservation of the location of significant points; and
e) Absence of features not contained in the original seafloor.

Capturing the bottom profile in this way has many advantages, but the 4th edition makes no reference to any form of along track sounding spacing

Beyond depth – the bathymetry model

Another section of SP44 that addresses errors is the section “Bathymetric Model Accuracy”. Despite the somewhat obscure wording of SP44 on this point, the term “Bathymetric Model” can be interpreted to mean contours derived from the measured depths. In other words, the seafloor is measured at points with error parameters as described in SP 44, Table 1, while between the measured points the seafloor is modeled by contours. Logically, these contours cannot have as high an accuracy as do the measured points, and Table 3 lists constants for the fixed and variable terms in the formula used to determine error values of the un-measured depths. These produce a vertical error 2 to 3 times tat at the measured locations. SP44 does not indicate how this is to be combined with the results from Table 1. Note that there is no weighting for the distance from the measured points, nor the measured points’ isolation or clustering. SP44 appears primitive in comparison with the results produced by other methods (for example Vanicek, 1999, Kielland and Dagbert, 1992) and it appears that SP 44 needs some revisions in this area.

Other uses

United Nations Convention on Law of the Sea (UNCLOS)

Ratification of United Nations Convention on Law of the Sea (UNCLOS) in 1994 brought with it the possibility for Coastal States to claim a juridical continental shelf beyond the 200 nautical mile-wide Exclusive Economic Zone, provided certain conditions are met. Of direct relevance here is the 2500m contour whose mapped position will, in certain cases, determine the outer limit of jurisdiction of a Coastal State. The 2500m contour is to be used as the line from which a constraining line can be constructed, at a distance of 100nautical miles seaward of the 2500m contour. This 2500m+100 line is one of two lines that must be combined to form a constraint on the outer limit of the area that a State can claim. The other constraint line is one “350 nautical miles from the baselines from which the breadth of the territorial sea is measured”. The two constraints are blended together by choosing sections of whichever is most seaward. Potentially then, any miss-location of the 2500m contour can substantially effect the area that could be claimed by a State beyond 350nautical miles. Like other depth measurements and contours, the 2500m contour will be displaced horizontally by an amount equal to the uncertainty in depth measurement divided by the cosine of bottom slope.

To examine claims, the Convention established the Commission on the Limits of the Continental Shelf (CLCS). This body has issued Guidelines (UN, 1999) on the evidence it will accept. The CLCS requires that submissions include estimates of error using the formula and values for fixed and variable error in SP44. Since it is unlikely that a lot of older data can meet the standard, and indeed the Standard proclaims itself to be for the future, the Guidelines may thus be requiring all Coastal States to collect new data for their claims.

The impact of technology

Positioning Capability

Moving from inshore to offshore, there is a progressively looser positioning accuracy demanded for each Order of survey described in SP 44. This appears anachronistic in the era of positioning satellites which are obliterating distance from shore as an issue (ad this week of 40cm position accuracy at ranges of 900km). The hydrographer's traditional safety net of being able to position data better than the mariner who used it could position his vessel is long gone: modern clients can use equipment that located them as well as the hydrographer was located. Each year sees the accuracies of these systems improved, to the point where even last years data are suspected of not being good enough. Why then have varying requirements for positioning?   Position with respect to WGS 84, what are charts on?

Mbes

Recommendations

When work commences on the 5th Edition of SP44, consideration should be given to the following recommendations. Indeed, it is hoped that publishing them will help move the IHO towards the goal expressed in the 3rd Edition of issuing SP 44 every 5 years.

1. The w/g that rewrites the standards should remember the point underlines in the ISO Technical Committee 211 (TC211) definition of quality: *The totality of characteristics of a product that bear on its ability to satisfy stated and implied needs.* (emphasis added) SP44 Edition 5 must satisfy the implied needs that the standard applies to all measurements of depth, whatever their use.

2. Bottom slope can be more important than depth measurement to overall accuracy achievable, and should be included

3. Instruction should be provided for along track sounding spacing in areas not having 100% Bottom Search

4. The standard should be altered to accommodate the many users want the same accuracy everywhere, not accuracy that degrades with depth

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TABLE 1

Summary of Minimum Standards for Hydrographic Surveys

ORDER	Special		2	3
Examples of Typical Areas	Harbours, berthing areas, and associated critical channels with minimum underkeel clearances	Harbours, harbour approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy	2m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth

(95% Confidence Level)				
Depth Accuracy for Reduced Depths (95% Confidence Level)	a = 0.25 m b = 0.0075	a=0.5m b = 0.013	a =1.0 m b = 0.023	Same as Order 2
100% Bottom Search	Compulsory	Required in selected areas (2)	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m	Same as Order 1	Not applicable
Maximum Line Spacing	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is greater	3-4 x average depth or 200 m, whichever is greater	4 x average depth