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TOWARD IMPROVED ACCURACY STANDARDS FOR HYDROGRAPHIC SURVEYING

by Stanley ALPER
and John D. BOSSLER (*)

During a routine review of hydrographic procedures, we became aware that the hydrographic survey standards published by the IHO [1] and our own agency [2] are not stated in terms of statistical parameters as is the case in most sciences, e.g. in geodesy. Digging a little deeper, though not exhaustively, we found that some of the published standards are either ambiguous, unrealistic, or not definitive. This is true for both depth and horizontal positioning standards.

DEPTH STANDARDS

Let us examine depth measurement standards more closely : present terminology, measurement processes and a course of action for improving these standards. The 2nd edition (1982) of the IHO Standards for Hydrographic Surveys, Book 1, contains the following for measured depths :

PART C — DEPTHS

SECTION C.1. — Measured depths

C.1.1. The error in measuring the depths should not exceed :

(a) 0.3 meter from 0 to 30 meters
(b) 1.0 meter from 30 to 100 meters
(c) 1 % of depths greater than 100 meters.

Figure 1 illustrates this in graphical form. The interpretation of these standards is complicated by the fact that there is no clear definition of the sea

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(*) Office of Charting & Geodetic Services, National Ocean Service, National Oceanic & Atmospheric Administration, Rockville, Maryland 20862, USA.

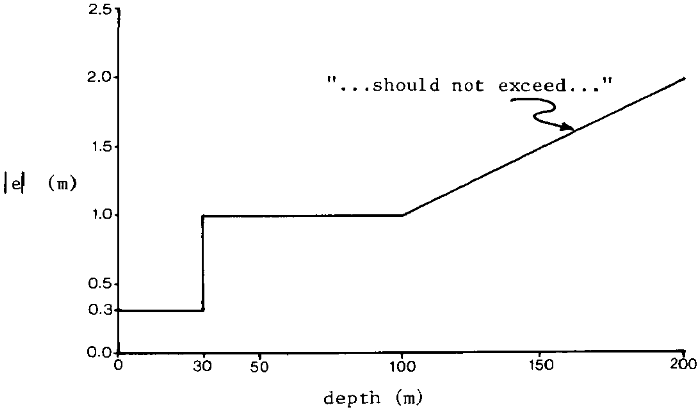

FIG. 1. — IHO standard for error |e| in measured depth.

bottom, so the "depth" is difficult to determine. For example, the bottom may be hard and relatively smooth with a distinct delineation between solid matter and water. It may be hard and rough with features whose vertical extent is in excess of the above error standards. It may be soft mud with a high concentration of suspended material which extends for a significant distance above the bottom. We are not suggesting that these bottom types comprise a proper classification for hydrographic purposes. They are sufficient, however, to make the point that more definition of bottom type may be required for a reasonable depth measurement standard.

The principal, though not the only, objective of a hydrographic survey is to determine safe navigable depths, especially in waterways and channels. It is in this context that some agreement is needed about what constitutes the depth for each type of bottom considered important. Since depth measurements are typically made by echo sounding, it is difficult to talk about errors in depth measurements unless we agree upon a definition of what is "bottom".

For navigation the implication of an error in charted depth differs depending upon the type of bottom. A ship striking a hard feature that is two feet too shallow for clearance might suffer structural damage and possibly severe consequences. The same ship might otherwise "clear" a hard bottom overburdened with several feet of soft mud even though "depth" is 2 feet shoaler than her draft. Therefore, for each type of bottom, we ought to define the depth measurement and depth error standards according to physical characteristics that constitute potential navigation hazards.

It is our contention that the absence of a statistical parameter renders the present depth standard somewhat unrealistic. Does the expression, "should not exceed", mean never exceed, hardly ever exceed, or not expected to exceed ? Our own hydrographic manual expresses the depth measurement standards as "allowable errors". The inference is that errors beyond those listed in our manual are unallowable. The reality is that even with modern, efficient, digital sounding systems for hydrography, one can't obtain an upper bound on performance for all bottoms that would meet a single rigid standard considered acceptable for navigation safety. There are two reasons for this.

First of all, the production of depth soundings is an "open loop" process. One can't test soundings with a go/no-go plug gage and reject those that fall outside rigidly defined limits as one would with manufactured parts. Nonetheless, one can design, test, qualify and manage the operations of depth sounding systems so that the probability distribution of the sounding errors they produce under specified environmental conditions can be predicted with some confidence. By managing and controlling the depth sounding process (through calibrations, periodic onboard system check outs, and sound velocity measurements) and by having an experienced hydrographer analyze the stream of depth soundings for anomalous indications, one provides assurance of the quality of the data, but still in an "open loop" sense. One can't be certain about the accuracy of any single depth sounding, but one can be reasonably confident about the distribution of errors associated with a stream of depth soundings.

The other argument for not putting a rigid limit on what might otherwise be an acceptable uncertainty for a depth measurement is that one doesn't have the luxury of making repetitious depth measurements at a point. In geodesy, for example, one can stay at a given point for sufficient time and usually under stable and benign conditions which allows repeated measurements to be made. The nice little microprocessors one carries along with one's geodetic instrument system allows one to compute the means and variances and to decide if it is necessary to take another set of measurements before leaving the field site. In geodesy it is also possible to check for measurement errors by various types of closures.

In hydrography, one can run cross lines and employ other procedures to determine if there is a gross error or drift in the performance of the system. The important point is that one can't repeat the depth measurement. Nonetheless, we can and do manage depth sounding systems such that we have a high degree of confidence in the statistical distribution of errors. The depth measurement standard should, therefore, be stated in statistical terms.

Referring again to Figure 1, it is seen that the graphical expression of the published standard shows that the "should not exceed" error at a depth of 30 meters is both 0.3 meter and 1.0 meter. We suspect this ambiguity arose because 30 meters is about the draft of today's deep draft vessels. The NOS Hydrographic Manual [2] has such an ambiguous discontinuity at 20 meters because it is based on an earlier edition of the IHO standards which were published in 1967, when there weren't so many deep draft vessels. On the face of it, the discontinuity might be acceptable if one assumes that the standard should be driven only by accuracy required for navigation safety and economy of operations. The reality is that standards are usually a compromise between what is thought to be necessary or desirable from the point of view of the user of the (information) product and what is technically and economically feasible to achieve. If the standard is set at a depth of 29 meters to be 0.3 meter, it ought to be practical to meet. If not, the standard won't be taken seriously. On the other hand, if the depth measurement process meets that standard, there is no reason why it should not do almost as well at a slightly greater depth, say 31 meters. The standard ought not to differ by a factor of three between depths that are slightly different but nominally the same (i.e., about 30 meters). Furthermore, we can't envision a hydrographic operation in which quality assurance procedures and controls would or should be relaxed significantly whenever the depth changed by only a few meters.

Considering these difficulties with existing standards, we suggest a course of action for improving them. Three of the things needed are :

1. Classification of bottom types important in hydrography; definition of where the bottom is for each bottom type in terms of bottom type parameters and with respect to navigation safety or impediment.

2. Development of a depth measurement standard (in statistical terms) that is unambiguous, and is a practical compromise between requirements for navigation and performance capability of modern digital depth sounders. This standard might be specified for hard flat bottoms or various types of bottoms depending on our success in defining where the bottom is for each type. Alternatively, we could consider one standard for hard bottoms and a relaxed standard for bottoms with a significant overburden of soft mud or silt.

3. Promote the acceptance by IHO of an improved depth measurement standard.

Applied research has already been initiated on the first item in NOAA's Atlantic Oceanographic & Meteorological Laboratories. On the second item, Capt. Wayne MOBLEY (NOAA, Ret.), just a few years ago, came up with a suggested depth measurement standard expressed in statistical parameters [3]. He identified

TABLE 1 [3]

Vertical Accuracy Goal (1 σ) d = depth

Error Source	Meters
Depth measurement (timed)	± (0.10 + 0.003 d)
Heave error	± 0.12
Pointing error (roll and pitch)	± 0.003 d
Tidal zone	
— measurement variation	± (0.06 + 0.003 d)
— rounding	± 0.05
Velocity measurement	± 0.002 d
— zone variation	± 0.002 d
— rounding	± 0.05
Draft measurement	± 0.06
— time variation	± 0.12
Settlement & squat	
— measurement	± 0.06
— variation	± 0.12
TRA rounding (*)	± 0.05
Tidal datum	± 0.06

(*) TRA rounding is defined as the uncertainty in transducer location arising from estimating its location to the nearest tenth of the measurement unit.

principal sources of both dynamic and static error in digital depth sounding systems, and he estimated and recommended a budget for the standard (one sigma) error for each of them as listed in Table 1.

Under the assumption that all of the sources of depth measurement errors are statistically independent and including an estimate for the standard error in measurement of the tidal datum, MOBLEY calculated the standard deviation of single depth measurements to be :

$$\sigma e = 0.28 + 0.006\, d$$

with both σe and d expressed in meters.

Captain MOBLEY suggested this as the depth standard for hydrography. Figure 2 shows the 68 percent bound (1.0 standard deviation) and the 90 per cent bound (1.64 standard deviations) in comparison with the present IHO standard.

It is seen that MOBLEY'S statistical standard is not as severe as the IHO standard. A statistical standard of the same type, but somewhat tighter than the one suggested by MOBLEY, could be adopted such that the 90 percent bound would be closer to the present IHO line. We would do so because our interpretation of "should not exceed" is closer to 90 percent than 68 percent. We ought then to assure ourselves that this standard is technically and economically feasible to comply with.

Accordingly, we are proposing that the National Ocean Service adopt the standard represented in Figure 3 pending an examination for feasibility of compliance. This standard is expressed as :

$$1.64\, \sigma e = 0.3 + 0.01\, d$$
$$\sigma e = 0.18 + 0.006\, d$$

In discussion of the above proposed standard with others, some concern was expressed that depth measurements might not be normally distributed. If, in fact, depth measurements were not normally distributed, it is still important that we require that most (say 90 %) of our depth measurements fall within a specified bound. This is what the proposed standard does. Nonetheless, to get some idea of the distribution of depth measurements, we have plotted a histogram for each of

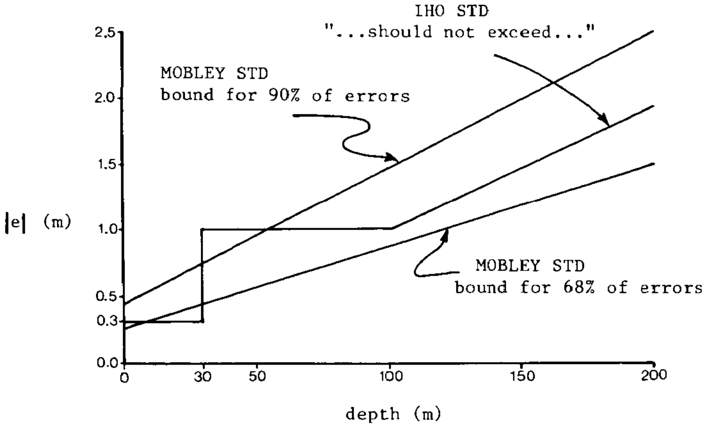

FIG. 2. — Comparison of IHO and MOBLEY standard for error |e| in measured depth.

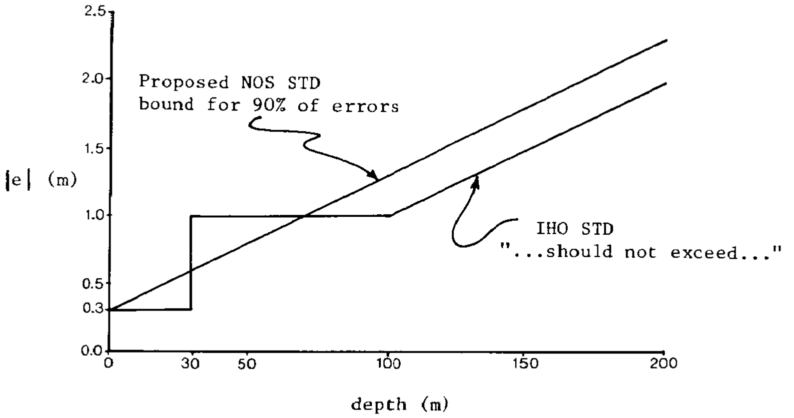

FIG. 3. — Comparison of IHO and proposed NOS standard for error |e| in measured depth.

two sets of depth measurement test data. One of these, Figure 4, is from a test [4] of a launch-mounted Ross echo sounder, north of Virginia Key, Florida, conducted in 1977. The other, Figure 5, is from a test [5] of a bathymetric swath survey system off Cape Disappointment, Washington, conducted in 1981. In both these tests, repeated passes were made and soundings taken over small parcels of the bottom predetermined to be relatively flat. It is seen in Figures 4 and 5, that the histograms, based on not especially large samples, are rough approximations to normal distributions. Tests for goodness of fit performed on each set of data provided no basis for rejecting the null hypotheses that each came from a normal population. The data in both instances were corrected for tidal variations over the duration of the tests. Furthermore, by inspecting Table 1 [3] and recognizing that most of the error components are independent, we conclude that the Central Limit Theorem applies and therefore we are dealing with normally distributed samples.

POSITIONAL STANDARDS

The published standard for horizontal positioning, while neither ambiguous nor unrealistic in the same sense as the present depth standard, does lack clear definition. The present IHO standard for horizontal positioning includes the following :

PART B — POSITIONS

SECTION B.1. — Horizontal Control

B.1.5. The position of soundings, dangers and all other significant features should be determined with an accuracy such that any probable error, measured

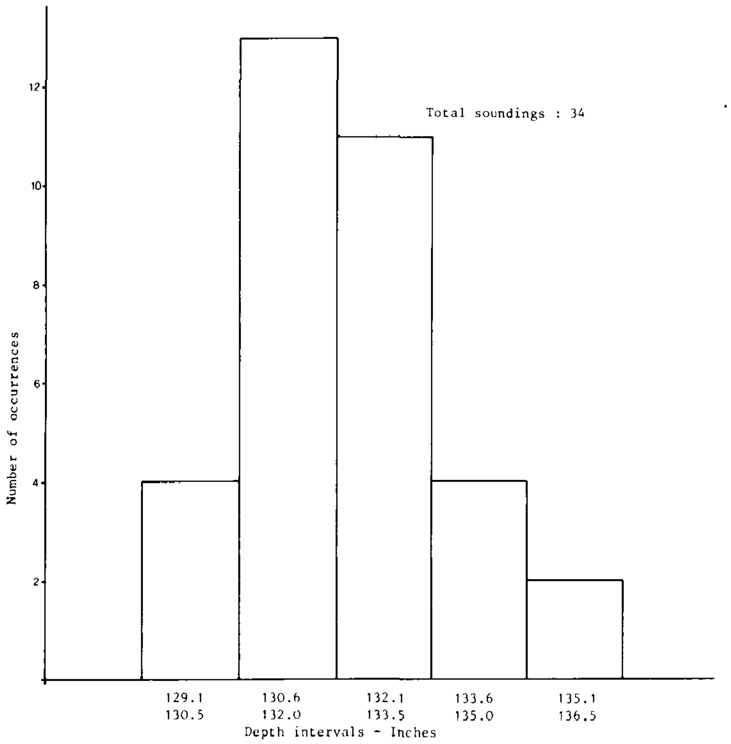

FIG. 4. — Histogram for depth measurements — Ross echosounder, Virginia Key, Florida, 1977.

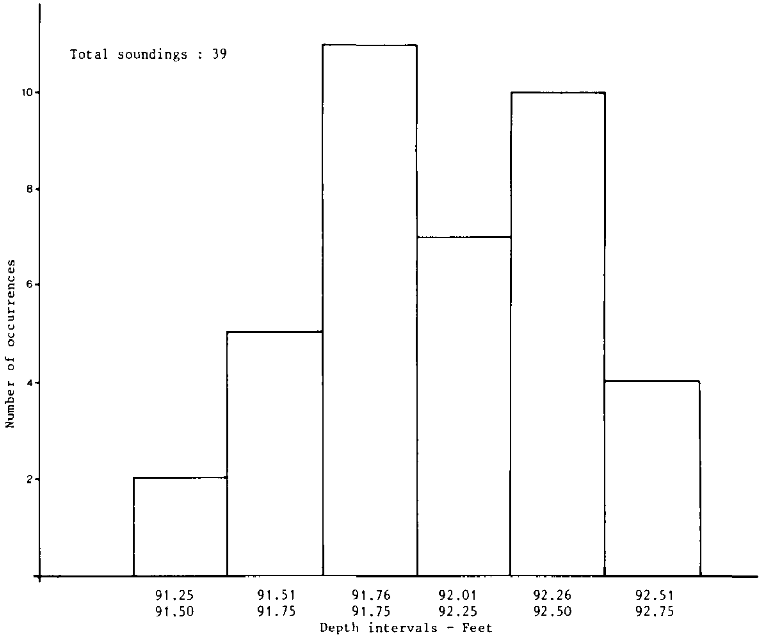

FIG. 5. — Histogram for depth measurements — BS^3 port vertical beam. Cape Disappointment, Washington, 1981.

> relative to shore control, shall seldom exceed twice the minimum plottable error at the scale of the survey (normally 1.0 mm on paper). It is most desirable that whenever positions are determined by the intersection of lines of position, three such lines be used. The angle between any pair should not be less than 30°.

Before considering that content of paragraph B.1.5. which is intended to be the position standard, consider first the second and third sentences, "It is most ... be used. The angle between ... less than 30°". These sentences have nothing directly to do with the position standard. They deal with survey practice. Regardless of whether this guidance is correct, it does not clarify or strengthen the position standard. These sentences may possibly be thought of as a procedural standard prescribed for a given positioning system or as procedural policy of a specific hydrographic agency. Furthermore, if the range error of a given range-range system and procedure is large enough, then an intersection angle greater than 30° may even be unsatisfactory. Procedural standards or policy in the use of positioning systems ought to be separated from the position accuracy standard if for no other reason than that they are not of the same genre. The main reason for keeping them separate is that there should be no inducement to confuse goal (position accuracy) with strategy (positioning procedure or practice) nor to subordinate the former to the latter.

Consider now the first sentence in paragraph B.1.5. The standard specifies that, "... any probable error ... shall seldom exceed twice the minimum plottable error ... (normally 1.0 mm on paper)". In statistical parlance, the term "probable error" means the error which half the errors in the population are expected to exceed and half are expected to be below.

The phrase, "... shall seldom exceed..." is said to be interpreted by some hydrographers to mean — shall not exceed 90 percent of the time. If that is what is meant, then the standard should be explicit because the phrase "... shall seldom exceed..." has no recognized definition. But, for the moment, let us accept it as meaning — shall not exceed 90 percent of the time. Then we would have the probable error shall not exceed twice the minimum plottable error 90 percent of the time (normally 1.0 mm on paper).

Even though one could combine "probable" and "90 percent" to have some definite meaning, there is still a certain lack of definition in the phrase, "minimum plottable error". In conversations with people who are in almost daily contact with hydrographic survey matters, we were given different interpretations of what this means — not just quantitative differences, but conceptual differences.

Finally, the qualifier "... (normally 1.0 mm on paper)" takes a poorly defined standard and tries to loosen it a little.

We submit that paragraph B.1.5. of the IHO standards is too subject to non-uniform interpretation and does not provide a sound basis for evaluating and qualifying hydrographic positioning systems. We propose that the standard should be revised as follows :

> The position of soundings, dangers and all other significant features shall be determined from field observations such that there is at least a 90 percent probability that the true position lies within a circle of 1.0 mm radius (at the survey scale), about the determined position.

The proposed standard contains two numbers — 90 percent and 1.0 mm. If there is not a consensus in the community on these specific numbers, they can be changed. However, absent any comments, C&GS plans to adopt this standard. Actually, it is sufficient to change only one (either one) as there is really one degree of freedom in the standard. As proposed above, the 90 percent "confidence circle" has a radius of 1.0 mm. Implicit in this is the size of all other confidence circles for the standard as written. If, for example, one simply replaced the 90 percent by 80 percent in the above standard, then the standard would be less stringent and a different family of confidence circles would be implied. Alternatively, one could maintain the 90 percent figure and increase the radius of the corresponding confidence circle for a less stringent standard.

Lest there be any concern about how to transform a knowledge of the error characteristics of range and azimuth measurement systems used in position determination and the angle of intersection between given lines of position into confidence circles, several workers [6], [7], [8] have developed models for so doing. The most recent of these, HOOVER [8], used numerical techniques to develop algorithms which avoid the use of probability curves, tables, charts, Bessel and other special functions. HOOVER has implemented and demonstrated the use of the algorithms on a microcomputer.

The existing models which generate confidence circles are based on the assumption that the probability density functions of the random error of the measurement systems are normal. We have drawn two histograms from readily available range test data for one of our present operational systems — the Miniranger III. These are shown in Figures 6 and 7. One hundred measurements were used for each histogram. Tests for goodness of fit on both these sets of data would support the assumption of a normal distribution for both the short-range and long-range cases.

As noted in the legends on the figures, these were static tests, i.e., both the transmitter/receiver (normally on a ship or launch) and the transponder were fixed and most of the path traversed was over water. The transceiver was situated atop a five-story structure, the transponder at short range at the end of a pier, and the transponder at long range at approximately the five-story elevation on the opposite side of Chesapeake Bay.

The wider variation in the short range case is possibly due to the combination of clutter and the higher signal strength in the vicinity of the transponder causing a mixing of reflections with the return from the transponder, differences in the two transponders, or possibly due to interference from another transceiver which was collocated with and making range measurements alternately with the other.

In regular operation, with the transceiver installed on a ship or launch, the situation is dynamic and measurement errors will include the effects of ship motion. The overall error will tend to be larger, but the contribution due to ship motion is not expected to be skewed. The use of motion sensors (roll, pitch) can provide data which together with attitude data can be used to make corrections for the motion. Such sensors, while useful in the reduction of the total measurement error, will themselves be subject to random errors and as such will add to the number of random components comprising the total error.

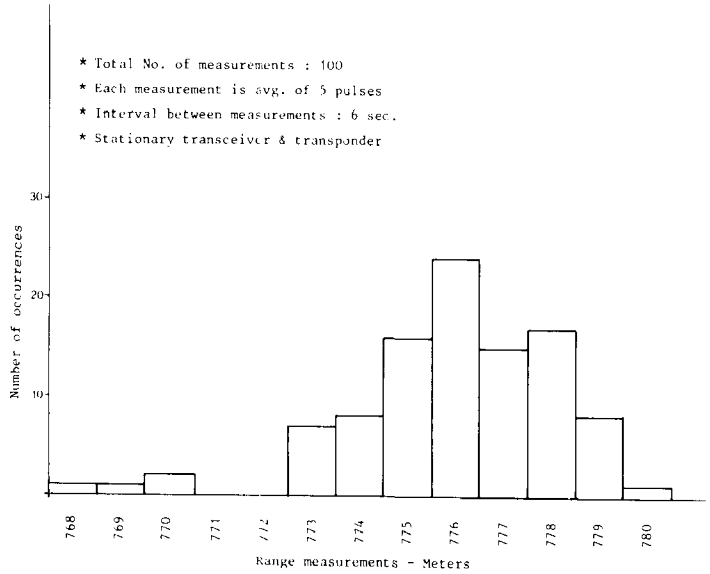

FIG. 6. — Histogram for Miniranger III range measurements. Lynnhaven Inlet, Virginia, March 1983.

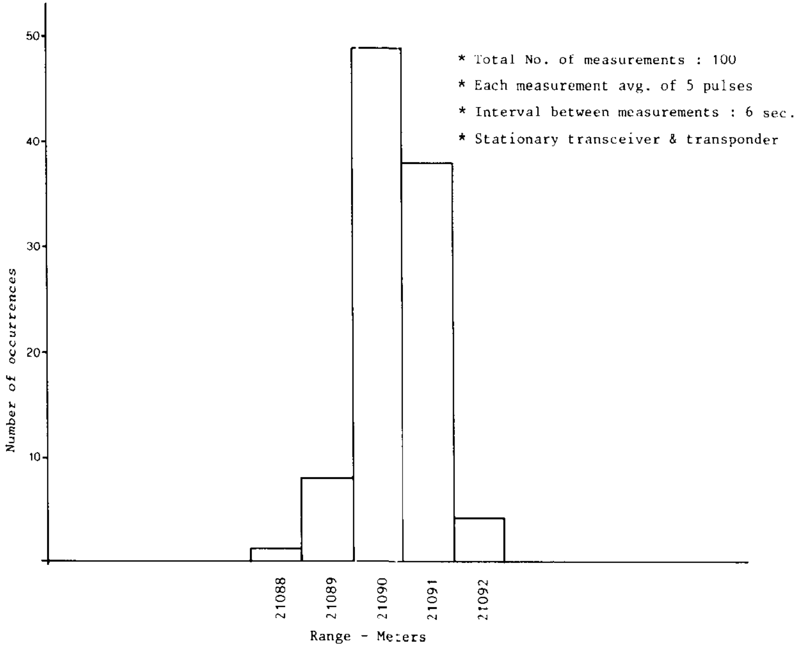

FIG. 7. — Histogram for Miniranger III range measurements. Lynnhaven to Hampton Roads, Virginia, March 1983.

Most of our tests of range and azimuth measurement systems have been under static conditions. We are now considering setting up a dynamic platform on which to mount transceivers for testing to get a better understanding of the random error distribution of ranging systems under dynamic conditions. It could also be used for evaluating the performance of azimuth measuring systems and their operators and also for operator training. The proposed standard provides a well defined mark against which to measure the performance of our present systems and against which to specify future systems.

In the foregoing, we have proposed improvements to both depth measurement and horizontal control standards. We would like to hear from representatives of other agencies interested and concerned with this subject matter and who would like to work jointly toward improving these standards. The opportunity exists for a significant contribution to hydrographic surveying.

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MARINE RESOURCES
THE SURVEYOR'S INVOLVEMENT

The sea areas have made a spectacular contribution to the world's hydrocarbon requirements. But the surveying profession was not equipped to exploit the opportunities offered. The traditional hydrographic surveyor was primarily concerned with depth measurement for navigational safety. A few, being also professional seamen, adapted their skills to the needs of offshore hydrography, but their numbers were inadequate to meet the demand, which was partly met by land surveyors, but chiefly by geophysicists, engineers, computer operators, etc.

It would be foolish to pretend that the surveying profession commands the same position at sea as it does so successfully on land. In the marine environment also, all branches of the surveying profession will have to work closely with the other professions involved. These teams could be involved in various activities — recovery of minerals from the seabed, development of fisheries, compilation of natural maritime resources, development of marinas and many other related fields.

Surveyors have already been involved with siting of offshore platforms, pipe laying, offshore terminals, large scale reclamations, etc. In the future, they will be associated with offshore energy producing projects such as offshore windmill platforms, wave energy projects, ocean thermal energy projects, tidal barrages and tidal power and offshore islands.

All these applications of the surveyors' skills and expertise will take time to develop and new training facilities will be needed. Unless, however, the profession responds to the existing challenge of Marine Resource Management and invests both financially and in manpower, its valuable potential will not be realised and inefficient, uneconomic usage will be made of the earth's marine resources.

(Extract from a paper by Rear Admiral D.W. HASLAM, presented at the CASLE Europe Regional Seminar held in Cyprus in March 1984).