HYDROGRAPHIC SURVEYS

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LAND measurement has always been with us. We don't know, but in all probability neolithic man had his own particular type of boundary markers to show the extent of his domain. We do know that Egyptian priests practiced some of the crafts of land measurement. Evidence of this is positive and a matter of record. A plan of an Egyptian noble's villa was found in the ruins of Thebes. There was also found, on the walls of a tomb in the same ruins, a representation of two chainmen measuring a field of corn. The earliest known land surveys of any extent occurred about 1300 B.C., when the Egyptians utilized the Great Pyramid in making cadastral surveys.

The history of the measurement of sea areas with resultant charting of sea routes is somewhat more obscure. We know that as early as 300 B.C. the early Greeks used a sort of log line for measuring distances between points of land, and prior to that in about 1300 B.C., the Chinese had discovered the value of a lodestone as a magnetic compass. Early charts were vague and inaccurate, made as they were from the use of crude astronomical instruments. It is thought that the first charts were made by Arabs in the Mediterranean Sea in Medieval times. They used the astrolabe discovered by Hipparchus in 150 B.C. These charts were not very accurate and left most of their sailing accuracy dependent on well-known landfalls. After the shape of the earth was established, and the great Mercator developed his method of conic projection, charting of sea routes became progressively more accurate. The use, first of the octant which in turn was followed by the sextant about the mid-18th century, did much to establish accurate marine charting. The sextant is still in use in many forms of hydrography, but its use is becoming more limited as various electronic methods of location are being employed.

So much for historical background. It is a large field and hours could be spent on it. I've treated it rather briefly as a sort of introduc-

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tory lead into the purpose of this paper. One more historical fact, I started working for the Corps of Engineers in the middle thirties. Methods used at that time had not changed for probably a century. What I'd like to bring out is the difference between the usual surveying methods at that time and the more modern methods gradually being incorporated into the Corps of Engineers' work.

Before we get into specific methods of hydrographic surveying it might be well to localize the functions of each particular government agency directly concerned with them. In the United States hydrographic surveys are performed by three Federal agencies—The U. S. Coast and Geodetic Survey; the Corps of Engineers, United States Army; and to a lesser extent, The Navy Hydrographic Office. The Coast and Geodetic Survey has the primary responsibility of charting all seas adjacent to its continental and territorial waters. As well as charting these waters, it is responsible for all primary control, both horizontal and vertical and any hydrographic work of any extent is referenced to this control. The Navy Hydrographic Office usually accomplishes all work inimical to Fleet movements, cooperating with the other agencies in final findings. The Corps of Engineers is responsible for improvement, and maintenance as required, of all navigable channels, both coastal and inland, and for the improvement of harbors and rivers. In connection with its work, it has improved the Great Lakes, Mississippi River, its tributaries, such as the Missouri and Ohio Rivers, and several lesser tributaries. As the needs of commerce demand, it deepens and improves harbors and channels to accommodate the larger ships constantly being built. For example, the five Great Lakes are now under study to provide connecting channel depths to its harbors consistent with the St. Lawrence Seaway, now under construction. A closer example of successive improvement is our own Boston Harbor, which has been deepened from an original twenty feet to 40 feet below mean low water. Several branch channels such as Chelsea Creek, which was originally a mud flat, the Mystic River, and Weymouth Fore River Channels have been deepened to accommodate deep draft vessels. The President Roads anchorage has also been deepened to 40 feet, which allows anchorage space for several deep draft vessels awaiting dockage. Needless to say, this takes a lot of field surveys. Since the greater part of my hydrographic experience has been with the Corps of Engineers, naturally most of my discussion will treat of past and present Corps of Engineers methods.

Surveys of harbors may be broken down into several categories. These categories may be defined as: surveys of harbors which have never been improved and in which improvement is desired, or proposed; surveys of harbors which have been improved and need further improvement; and periodical surveys for maintenance purposes only. One other category that I should mention now is one that is practiced infrequently but none the less important. It is in surveying for obstructions and sunken wrecks that may impede navigation. In the category of unimproved harbors, which in New England is now confined to fishing and recreational boat harbors, it is first necessary to establish vertical and horizontal control. Vertical control is the easier of the two, and usually obtained by ordinary leveling methods to establish the plane of MLW from the nearest Coast and Geodetic Bench Mark. A tide staff is then set at mean low water. In some instances, such as the Cape Cod Canal, it was necessary to set up automatic tide gages at different points in the canal. It was found that as the canal was progressively widened from its original 100 feet to its present width of 480 feet the range of tide fluctuated with its width. This was due to different tidal ranges on opposite ends of the canal. The eastern entrance has a mean range of 9.4 feet and the west entrance a range of 4.5 feet. So, naturally, the range fluctuated as the gap widened.

The next step is horizontal control. Reconnaissance of the area to be charted is made both by field observations and examination of available maps and charts. Tentative points are selected, with a view to establishment of a good triangulation network and the necessity of being able to observe the open parts of the harbor where the hydrography is to be secured. Triangulation is then effected, efforts being made to include all Coast and Geodetic points for overall control. The control is usually integrated into the state coordinate system, such as transverse Mercator for Maine and the Lambert polyconic grid for Massachusetts, Rhode Island and Connecticut. Third order accuracy in triangulation is usually obtained as the harbor areas are small enough for this accuracy.

Next in order sounding is effected. A sounding crew for small boats usually consists of three men in a boat, an oarsman, leadman and notekeeper, two transitmen on shore and a man reading the tide staff. Several different methods of obtaining the hydrography may be employed. Shore flag ranges in pairs may be erected at regular intervals about normal to the natural channel lines, and the boat rowed or propelled at a slow pace along the projection of these ranges. The slow pace is necessary to avoid trailing of the lead which could cause an appreciable error. In such cases only one transitman is necessary. The boat is established on range and sounding begins. The sounding man establishes a cadence or rhythm to his soundings, taking them at regular intervals, usually 6 per minute, and the boat's location is usually taken at half or full minute intervals. The transitman has oriented his instrument to some triangulation point and reads the azimuth to the boat at a signal from the note keeper who waves a colored flag. Strict adherence to range lines is necessary, for any displacement of the boat off range results in considerable error. Variation in colors of flags determines the intermediate minute, five minute and 10 minute intervals on the sounding range. These color variations may be red for even minutes, white for odd minutes and red and white for 5 minute intervals. Tide readings are taken continuously while the survey is being accomplished.

Ranges fixed by signal flags on shore are not always employed. Chiefs of Party with long experience can select natural ranges and keep control of the survey within the desired limits. In this case two transits on shore or two sextants in the boat can be used. Advantage of this method lies in accurate locations. In localities in which large areas of open water are involved it is usually more practical to have two sextants in the boat. In connection with this method of securing location by sextant, sometimes what is known as a sextant circle chart is employed (sextant circle slide). Three triangulation points are utilized for this method. The points selected are joined together by straight lines. Using one end point and the mid-point, a perpendicular bisector is erected on the line between two of the points. To scale, the natural tangents of angles which will have circles containing the two points and which traverse the area concerned are then plotted on the bisector. Arcs of the circles are then plotted in the area. After this, the mid-point is connected to the third point and arcs drawn in a similar manner. Thus, the area being surveyed has two sets of concentric arcs intersecting each other. If care in the selection of points is taken the arc intersections are sharp enough to make the plotting of two simultaneous sextant angles quickly with sufficient accuracy. In narrow areas, with careful selection 4 points may be used. The advantage of this system lies in the fact that the survey can be contained solely in the boat and the chief of party is aware at all times of his location and whether or not he is getting sufficient coverage for his survey.

After all soundings have been taken, probings to determine the nature of the bottom are in order. Probing essentially means pushing a pipe through the bottom to determine the extent and nature of the material underlying it. In the New England Division, probings are taken from a small barge, 50′ × 20′. Probings are taken by either jetting or driving. In jetting a stream of water is forced through a one-inch pipe and pushed by hand to the proposed grade or refusal, whichever is encountered first. Drive probings are taken by counting the number of blows necessary to drive the pipe per foot into the bottom without jetting, thus determining the relative hardness of the bottom. Prior to dredging, core samples are usually taken in order that the nature of the materials may be known.

This completes the survey for a new harbor which has never been improved. Supplementary topography may be necessary to show shore installations, high water marks and general layout of the harbor. If not available from local maps such topography is taken, as it is very necessary that all marine terminals and shore installations be fixed accurately in relation to the hydrography already accomplished.

The same procedures are followed in harbors which have been improved and need further improvement, except that both horizontal and vertical control have already been established, and it usually needs only reestablishment of some points that may have been destroyed or have been subject to the usual ravages of nature. In the case of further improvement, not as extensive surveys are required. Channel lines are usually well defined and unless change is contemplated sounding ranges are taken at 100-foot intervals to cover the limits of the defined channel. Enough soundings are taken beyond channel limits laterally to cover specified side slopes, 1 on 3 for ordinary materials and 1 on 1 in rock. Probings for possible ledge excavation are also taken. If ledge is encountered above the proposed grade, then sufficient probings are taken to make an accurate determination of the amount of ledge to be removed. As mentioned before, probings are taken from a flat barge 50 feet long and 20 feet wide. I might mention at this time that the New England Division has recently built itself a new barge for this work. It is self-propelled by means of a 50-HP Murray and Trequrtha engine. Two Sprague-Henwood sampling units are mounted on each side of the barge so that probings may be taken on either or both sides of the barge simultaneously. Probings for quantity estimates of rock are taken on 10×10 or 20×20 foot centers. Location is established by means of shore ranges. Parallel back and front signals are placed about normal to the channel lines. Similar ranges are placed longitudinally in the channel. Range intervals are determined by the accuracy of the estimate required, usually 10′ by 10′. If sufficient range ground is not possible for parallel range ground, some outstanding object, such as a spire or chimney back of the shore line, is located and the ranges fanned from that point.

After the dredging has been accomplished, soundings are taken to determine the quantity of materials taken out. Soundings are taken as near as possible along the same ranges as used prior to dredging so that comparison can be made. But, in cases of excavating for ledge or channel bottom composed of very hard materials which may, due to the inaccuracies of dredging and inability to see any sub-aqueous high points above grade, one more refinement is added. The channel is swept to the designated grade. By sweeping, it is not meant that a large rake or similar object is trailed along the bottom to drag down any high points; although this method is sometimes used by dredging companies to knock down high points or loose piles of rock projecting above grade. Sweeping in surveying terms means suspending a light T-Bar to the designated grade and traversing the whole section with it. The bar is kept at grade by relaying each tidal change from shore. If a high spot is encountered its height above grade is determined by sounding and its location determined by either range intersection, or transit locations. The 50-foot barge is used for this purpose. Two 25-foot T-Bars are suspended from the barge with graduated chains at either end. Four men tend the two bars and after a little experience can determine the type of shoal and its extent. The barge is allowed to drift with the tide normal to channel limits. Range on the channel limits is ordinarily set on a combination of land signal and a range buoy close to the channel so that sensitivity of ranges is at a maximum. The propulsion unit on the barge keeps the stern on range laterally and outboard motors on the side are utilized to overcome adverse wind or wave action. After a channel is swept clean, a set of ordinary soundings for estimate is made.

Sweeping for wrecks or obstructions is accomplished in the same manner as for dredging, except that a greater width of sweep is utilized. This method, called wire dragging, utilizes two launches, about 40 or 50 feet in length. A length of wire cable called a drag-wire, about 1000 feet long, is placed on one of the launches. This wire has beckets or ring bolts fastened to it at 100-foot intervals. Eleven buoys with wells running through the entire length of them, and a small hand reel on top, are also put on the boat. A graduated cable is reeved on the reel. Two 300-pound weights and nine 100-pound weights are also on the launch. In setting up dragging operations, one boat carries all the equipment. For setting operations the second boat comes alongside and fastens a tow line to one end of the 1000-foot wire. It then proceeds underway laterally across the area to be swept. In the meanwhile, a 300-pound weight is attached to the end of the drag-wire and one of the buoys with the hand reel and wire. As the drag wire is payed out, buoy and the 100-pound weights are fastened to the drag-wire at 100-foot intervals, the final end having the remaining 300-pound weight. A small boat then visits each buoy in turn letting down the drag-wire to the grade of the channel or in deeper waters usually to 50 feet. Then the drag is towed in a 1000 foot swath in the locale of the reported obstruction or wreck. Locations are taken by double sextant angles. If reporting is fairly accurate as to location, it seldom takes more than two or three passes to locate a wreck. The wreck is then accurately located and a buoy set adjacent to it. The Coast and Geodetic Survey often uses this method to locate high spots in specific localities. Successive passes are made on the location, the drag being raised a foot after each pass until a pass is made free of shoal.

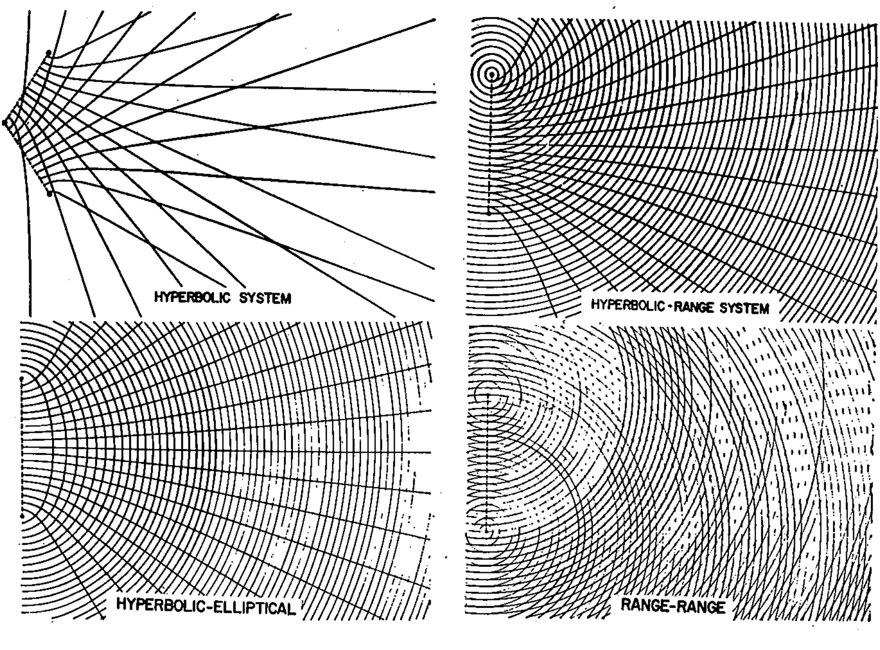
So far, we have talked only about lead line surveys and ordinary surveying instrument methods of obtaining locations. The lead line is gradually disappearing and echo sounding apparatus is superseding it. Echo sounding apparatus can be portable, operated from a rowboat or small power launch with 6 or 12 DC volt battery power. It can also operate from a larger launch with a 115 AC power source from a motor generator. Essentially the system employs a transmitter for the output of sound at a certain decibel value. The sound is relayed to the bottom, picked up by a receiver and amplified to produce an electrical impulse on a sheet of carbon backed paper, which is placed on two rollers normal to the striking arm. The interval between the sending of the sound and the receiving of it is plotted graphically on a continuously moving sheet of the previously mentioned carbon backed paper. The paper is so calibrated that the arc made by the impulse corresponds to the depth. About 200 soundings per minute are taken, giving a profile of the bottom over which the boat is passing. A mechanical device can change the position of the paper in order to compensate for tide. Thus the soundings appear on the paper automatically reduced to the plane of mean low water.

A further refinement is effected by the use of walkie-talkie radios. With one set on shore and one on the boat, constant communication is established between the tide man and the boat. Each tenth change of tide is reported and set on the depth finder and any unusual happening that may occur on shore can be reported directly to the boat.

Locations of this method of sounding have, until recently, been done as previously described, usually with transits or sextants at stated intervals. However, this system of location has its limitations, particularly in open waters where fixed points are fairly distant and obscured by fog or haze. A system of radar or continuous wave radio reflections to obviate some of these limitations on location has been developed. It was first used in the Norfolk District Corps of Engineers and has been employed in Hampton Roads and on the James River for the last five years.

This system employs continuous radio waves and depends on the measurement of the relative phase between continuous wave signals. The system consists of three fixed radio relay units or stations and one set of recording or indicating apparatus. The equipment for each fixed relay station includes a receiver, a constant output amplifier and a radio transmitter. All are packaged in a single unit with two 6- or one 12-volt battery for power. The relay stations are placed at triangulation points on the shore. The indicating and recording instrument, called the mobile transmitter unit, is placed on the survey launch, usually a 50-foot or larger boat. The mobile transmitter unit is a continuous wave transmitter with a power output of 10-watts. It transmits an unmodulated signal on 1.738 Mc, the frequency obtained by application to Federal Communications Commission for this system. A reference transmitter is conveniently placed so that it can be readily received by each of the relay stations.

In order to indicate the position of the mobile transmitter, which remember is in the boat, it is necessary that all three relay stations be placed in operation. A signal is then broadcast by the mobile transmitter and received by each of the relay stations. The reference transmitter then transmits a continuous-wave signal which is also received by each of the three relay stations, where it heterodynes with the signal from the mobile transmitter and is reflected back to it. The phase relations or phase counts are intercompared continuously. The position of the mobile station with respect to each of the relay stations is determined by the phase counts. The phase relationship of two stations is constant along the path of a hyperbola which has the two relay stations as its foci. Thus, if the mobile transmitter moves in a



COMPARISON OF AREAS OF HIGH PRECISION
WITH VARIOUS SYSTEM CONFIGURATIONS

hyperbolic path with respect to two of the relay stations, it has a constant phase between the two stations. Any deviation will give a different phase which is recorded on the phase indicator. The third relay station in connection with one of the other stations forms a second path of hyperbolae with reference to the base line between them. The end of this base line is referenced to the first base line. Thus, moving in any direction in the area covered by these two systems can be detected by comparing the phase of one pair of stations against the other.

In practice, quite a lot of preparation is necessary for this type of survey. The relay hyperbola stations have to be selected with care so that the segments of the hyperbola approaching a straight line would fall within the area to be sounded, and that the systems would be as near as possible at right angles to each other. The system is very practical for areas in which recurrent surveys are made and where comparisons of surveys can be made.

I'd like to cite one example of its practicability and economy. In Hampton Roads, Virginia, about 10 miles of deep channel is now being dredged. Dredging is being accomplished by a sea going hopper-dredge, the "Goethals." This dredge has a capacity of 5000 cubic yards of materials. Instead of disposing the spoil at sea as is usually done, it was determined that a nearby spoil area adjacent to the main channel could be utilized more effectively and economically. The spoil is transferred to a hydraulic rehandler and pumped to a diked-in spoil disposal area. Dredging of the channel is being accomplished by sections. Each section is brought down to grade before another section is started. A round-trip from dumping grounds to the dredging area and return averages about one hour. As the dredge works 3 shifts or 24 hours five days a week it is discernible that quite a large amount of material is removed every 24 hours and it is necessary to know all about it in a hurry. Consequently, a hydrographic party must spend at least part of every day keeping progress over the dredged sections. This is necessary not only to see that the dredge does not leave any shoal areas, but also to be sure that the dredge is not digging too deep a channel. Therefore, the dredge must often be shown the progress of its work.

With prior methods of sounding a lot of time would be expended sounding. Then the sounding record would have to be forwarded to the office for plotting and a plan showing the results forwarded to the dredge. The minimum time for this procedure would be about a week. The Raydist system reduces this time considerably. By use of a piece of vellum over a chart of the phase system, soundings can be taken direct from the chart and as the different phase intersections are also shown on the echo-sounding graph, plotting becomes merely a writing down of numbers on the vellum. It is reported that a day's work can be plotted in about three quarters of an hour. Besides this shortening of time in plotting, other advantages have been shown for this system. As the system does not depend on visual observations, the sounding can be accomplished in fog or hazy weather, or if need be, at night. The dredge also locates itself by means of this system so that with both the dredge and survey party using it the chance for error is minimized.

The Corps of Engineers does not believe that the ultimate in sounding methods is achieved by this system. At the present time research is being made whereby the echo sounding chart may be fed into a digital or analog computer and an estimate of the amount of materials be made directly from the chart, obviating the usual method of plotting and planimetering.

Another device that is being investigated by the Corps is called a Tellurometer. It consists essentially of two portable microwave units mounted on tripods. One is a master station which operates on radio microwaves of 10 cm. The master station is set on a known point and the remote station on the point to which a measurement is desired. The set is then adjusted for the particular meteorological conditions prevailing in the locality and placed in operation. The linear measurement is obtained by means of measurement of the waves reflected back from the remote station. Accuracy of three parts in a million or ± 2 inches in 35 miles have been reported in recent tests.