SOFALA BANK SURVEY
BY THE MOZAMBIQUE HYDROGRAPHIC SURVEY

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The Bank of Sofala is the name given to that part of the continental shelf of the coast of Portuguese East Africa that stretches from the Bazaruto Islands to a point slightly north of the Zambezi Deep.

The Bank varies in size, sometimes extending a distance of 60 to 70 miles and covering an area of more than 10,000 square miles.

As the port of Beira, which is becoming increasingly busy, is situated in this region, a close knowledge of the Bank is a matter of enormous and growing importance, particularly in view of the fact that there are in this area a number of shoals dangerous to shipping, and it is imperative and urgent to establish their character and position. For these reasons, the Mozambique Hydrographic Survey seriously contemplated the survey of the Bank, but local difficulties which arose through lack of suitable means for carrying out this work necessitated several postponements.

Weather and sea conditions, as well as the extended area of the Bank, made it extremely difficult to place floating beacons, and as the nature of the currents is little known in this area, it was not possible to take sufficiently accurate soundings, based on astronomical positions, for the drawing of charts. Developments in radio-acoustical methods would now allow for a satisfactory solution of the problem — taking into account the experience acquired in similar cases, such as that of the George bank — but in view of the recent appearance of modern radio-position-fixing methods, it was finally decided that one of these should be used. In choosing between the different systems available, it was necessary to bear in mind not only their technical characteristics, but also the conditions of the region in which they were to be used. The requirements called not only for strict accuracy and sufficient range, but also for wide mobility in cases in which the work required frequent displacements in areas where there were no means of communication and where the transport of equipment had often to be undertaken by sea and necessitated landings in small, inaccessible rivers with bars or even on unprotected parts of the coast.

Finally, a « Raydist » system (Type E — 100 watts power) was acquired with which the survey in question was carried out.

I. — *General Principles of the Mozambique Hydrographic Survey's System.*

Although this system has already been described in the Review for November, 1949, reference will be made once again to its basic principles before the work already accomplished is described.

The system is based on the measurement of the difference in the phases of the low-frequency signals obtained at fixed stations by the use of heterodyned signals of slightly varying frequency containing the following basic components :

1) *A mobile station* placed on a site of which the position is already known (e.g., a ship, small craft, etc.) and transmitting a signal on a continuous wave of f = 2641.6 Kcs. frequency;

2) *A reference station* placed in any fixed position and transmitting a signal on a continuous wave of f = 2642.0 Kcs frequency;

3) *Three relay stations* placed in fixed positions having well-known co-ordinates where, from signals received simultaneously from the mobile station and the reference station, signals of frequency $\Delta f = f' - f = 400$ cps are obtained by heterodyne and, in their turn, are transmitted to the main station on MF circuits of 36.1, 36.9 and 38.7 MC frequencies ;

4) *A master station* where the MF signals transmitted by the relay stations are received in unmodulated form, the 400 cps signal phases thus obtained being compared in couples.

Mathematical analysis shows that the phase differences so obtained are functions of the system's parameters and of the distance differences between the mobile stations, and are expressed by the following formula :

$$\psi = \frac{\omega}{v}(r_0 - r) + K$$

In this formula, $\omega = 2\pi f$, v represents the transmission speed of the electromagnetic waves, r_0 and r are the distances between the mobile station and the relay stations, F_0 and F_1, while K is a constant. In view of the fact that ω and K remain constant, the phase difference is solely a function of the distance differences, and the geometric loci, for which ψ = a constant, are hyperbolae with the same foci, F_0 and F_1.

If two pairs of stations supplying ψ_1 and ψ_2 values are used, it is possible to determine the position of the mobile station in relation to the relay stations within a system of hyperbolic co-ordinates. It is interesting to note that ψ is independent of the initial signal phases, which is an advantage as it means that there is no problem regarding phase relations, the stations being operated independently of each other.

The results are not stated in terms of ψ, but in hyperbolic lanes and fractions. Given the well-known, simple relations and the selection of the K constant so that the fixed hyperbolic net can be numbered from the focus F_0, the terms can be expressed as follows :

$$H = \frac{(r_0 - r) + m}{\lambda}$$

H representing the number of the hyperbolic lane and m the lenght of the F_0 F base.

As far as the position of the master station in relation to the other component parts of the system is concerned, two different types of operation are involved, these being either the navigation system or the homing system.

In the first case, the master station is placed on board ship like a mobile station ; in the second case, it is placed in any fixed position, but with radiotelephonic contact with the ship so that navigation can be effected along the sounding lines. The navigation system is very convenient, but the homing system allows for much greater range, so when choosing between the two, the decision must be determined according to the particular problem on hand.

II. — *Principal characteristics.*

It is of interest to know the principal characteristics of a system of this kind, which are: range, sensitivity and accuracy.

With regard to the *range*, bearing in mind the composition of the system and the principle on which it works, it is obvious that for its operation to be possible, the relay stations must have a good reception of the signals from the reference and mobile stations, and the master station must have a good reception of the signals from the slave stations. The study of these two circuits, in the context of local conditions and the characteristics of the commission's equipment, shows that, theoretically, the navigation system can be operated to a range of about 80 miles, and the homing system to a range of about 140 miles. In practice, a range of rather over 50 miles was achieved with the former, and 120 miles with the latter, which proves that the theoretical claims of the system are easily attained.

The *sensitivity* of this system, that is, its ability to measure small shifts in position can be estimated by the dr/dH quotient derived from shifts along the base which can be easily calculated as follows:

$$dr = \frac{\lambda}{2} dH$$

This indicates that the sensitivity is as great as λ is small. In the case of the Mozambique Hydrographic Commission, λ = 114 meters and the smallest division of the scale dH = 0.01 corresponds to a shift along the base of 0.57 m., which indicates the sensitivity of the system.

The *precision* of the system is dependent on the systematic and random errors that are characteristic of it.

When considering, first of all, the systematic errors, which are caused, chiefly, by the decrease of the surface waves, the presence of the induced field and the assigning of a false value to λ, it should be noted that the errors brought about by the first of these causes are very slight and can be ignored in the course of general application, while those brought about by the presence of the induced field are only apparent when operating very close to the relay stations and can, therefore, be regarded as non-existent for distances greater than 10 λ.

The third cause, however, is very important because the assigning of a false value to λ has the same effect as would be produced if the whole calculated hyperbolic net were displaced with respect to the actual net. Consequently, it is essential to know the most exact value of λ. If the value of the transmission speed is correctly ascertained, it should be easy, once f is measured accurately, to calculate λ on the basis of $v = \lambda f$. If this is not the case, then λ should be computed by other means.

Fortunately, the system itself allows for the calculation of the value of λ under actual working conditions, and the operation which should be applied and by which this value is determined is called « calibration of the system ».

If, through points A and B, a mobile station crosses the two extensions of a known base $F_0 F = m$, a reading of H_A and H_B having been obtained in these two points, then the difference in these readings represents the length of base measured in hyperbolic beams position lines of average wave lengths, for which the following formula applies:

$$\frac{\lambda}{2} = \frac{m}{H_A - H_B}$$

The base line extensions are, in fact, two debased hyperbolae of the system corresponding to a maximum and a minimum of F, the readings in question being easily arrived at as they correspond to the time that the needles of the phase meters go into reverse.

This operation is indispensable when employing the system for the first time, and it should be repeated a certain number of times so as to arrive at the closest value for λ under average local conditions.

The systematic errors having been eliminated as much in the application of the corrections as for the calibration, there remain the random errors which affect the determination of the position. These errors, in their turn, are dependent on technical factors which determine the stability of the system, that is, the error which affects each of the co-ordinates through which the position is obtained and the geometric factors which determine the manner in which these errors are spread to the various points of the field of application.

As far as the technical factors are concerned, if it is accepted that the errors of frequency produce in each circuit a correlation factor equal to one, and that the transmission speed errors are independent, then the terms for the typical error of the system, σ, will be stated by the following formula:

$$\sigma^2 = D + E (r_0 - r)^2$$

D and E being constants dependent on the characteristics of the system and indicating that its stability diminishes as one proceeds from the centre of the base towards its extremity. This variation, however, is small and, for practical purposes, can be considered a constant. The degree of this error can be easily calculated as it is governed by the scope of the system and by the extent of the errors df/f and dv/v. Disregarding df/f compared with dv/v as being negligible, and accepting a base m = 100 km. (with an error of dv/v = 0.00001 corresponding to an instability of dP = $\pm$ 2 mb for pressure, of dT = $\pm$ 2° for temperature, and of = $\pm$ 2 mb for actual tension of water vapour), the factor $\sigma = 0.01$ is arrived at, and with dv/v = 0.00005 (corresponding to an instability of dP = $\pm$ 10 mb, of dT = $\pm$ 10°, and of = $\pm$ 10 mb for the meteorological components), the factor $\sigma = 0.05$ is determined.

These two examples lead to the conclusion that, as far as the applications are concerned, it is essential to be extremety accurate, to employ for v a value corresponding to actual local conditions, and to gauge the meteorological components P, T and e with the utmost exactitude; on the other hand, as far as the hydrographic soundings are concerned, it is acceptable to use for v an actual value corresponding to local conditions, because a variation in the meteorological components, such as has been outlined in the second example, gives ample coverage for the variations encountered in the course of the work and allows for an error which is quite acceptable in this kind of application. This justifies the course followed in calculating the hyperbolic nets in accordance with a mean value for λ without applying any correction whatsoever to the measured co-ordinates.

The geometric factors referred to above result from the nature of the system according to which the standard error, σ, recurs in any point P multiplied by the hyperbolic expansion factor, cosecant $\frac{\gamma}{2}$, γ being the angle containing the base from P and (on account of the position error produced by the re-section of the two geometric loci) depending on the re-section of the angle θ.

The combination of these two facts leads to the mean square error of the point $\varepsilon\, \rho$ being expressed, in terms of the hyperbolic lanes, as follows:

$$\varepsilon\, \rho = \frac{\sigma}{\text{Sin}\ \theta} \sqrt{\text{cosec}^2 \frac{\gamma}{2} - \text{cosec}^2 \frac{\lambda 2}{2}}$$

III. — *The utilization of the system.*

To use this system, it is necessary that charts, on which the respective hyperbolic nets are outlined, be available. In principle, it is possible to use any kind of projection, as the calculation of the nets is made in geographic co-ordinates and the hyperbolae are plotted point by point on the required charts. Strictly speaking, this calculation should be made on the ellipsoid, but the difficulties of elliptic geometry can be avoided by the substitution of spherical, or even plane, co-ordinates.

The first substitution is possible when projecting the ellipsoid properly on an appropriately-selected sphere, and this solution is well suited to an extended area in which the calculated nets involve long distances.

A second simplification is based on the application of the Legendre theorem which in plane geometry introduces the correction produced by spherical excess. This is a solution which is suitable for intermediary regions where the spherical excess should be taken into account and where the distances are as yet not too great. Finally, in the zone closer at hand, the spherical excess cancels itself out and the equations of plane geometry can simply be applied. These analytical methods are, however, very laborious, and their application is not justified by the time and effort required, except in the case of the wide-range, fixed systems where the use of a selected projection is convenient.

An alternative method consists in choosing for the area of the work a projection in which the linear reduction modulus remains appreciably constant throughout the system's field of application.

Also, if the scale of the work allows, the net can be plotted graphically.

This latter method was adopted by the Mozambique Hydrographic Survey. The projection used in the plotting of the nets is an American polyconic projection in which, for the latitudes of operation and for $\Delta L = 1°$, half of the maximum angular deformation is shown as $\Omega < 15''$ and the relative variation of the linear reduction modulus is shown as $d\tau/\tau < 0.00015$, these conditions allowing for the application of graphic methods. The existence of suitable tables and the easiness of the constructions are, however, factors which were taken into consideration when making the selection.

The sounding plan is plotted on the chart drawn with hyperbolic nets and the soundings are laid out along suitably-spaced, straight lines directed according to the coastline, the values of the hyperbolic co-ordinates of each sounding being recorded in tabulated form.

In following the directions of the system, the ship is steered according to the sounding lines, every endeavour being made to follow as accurately as possible each sounding, which is easy enough, given the continuously known position of the vessel.

Before starting sounding operations, it is necessary to line up the system by verifying the direction of the phase-meter movement and by showing the initial co-ordinates on the meters so that when these operations are completed, the position of the mobile station in automatically and continuously shown.

IV. — *Work accomplished.*

The part of the Sofala Bank already sounded is shown in Figure 1. The oblique lines indicate the soundings carried out according to standard methods (by observation of horizontal angles), the vertical hachures indicate the soundings made by using the system as a navigation instrument, and the horizontal hachures indicate the soundings made by using the homing system.

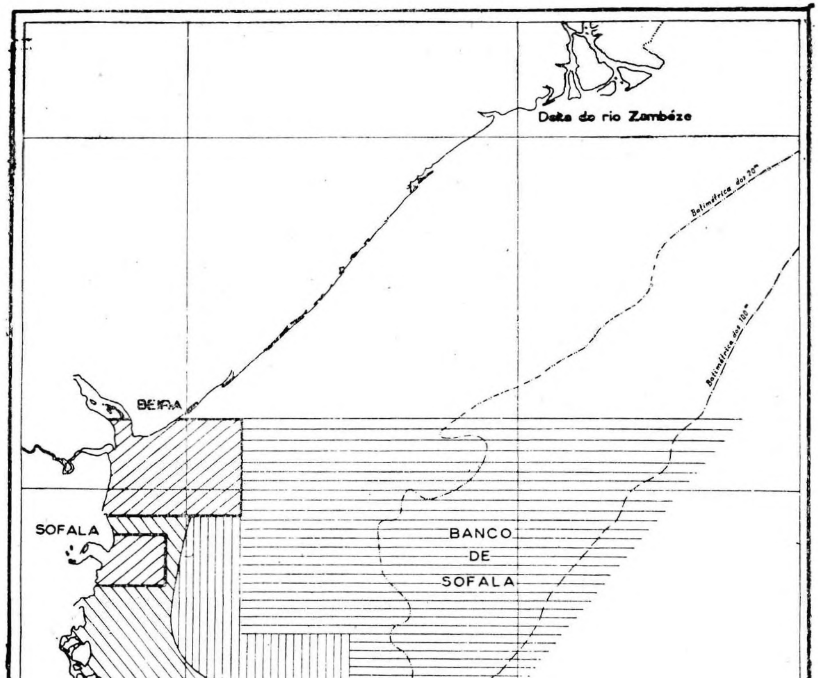
The total area sounded to date is about 7,000 square miles, of which more than 5,000 were surveyed by means of « Raydist » equipment.

The positions selected for the stations along the coast were chosen in conditions such a way as to avoid mixing courses in the journeys between the mobile station and the slave stations, and to obtain the best possible line-crossing in the zones to be sounded. Allowing for a typical error of $\sigma = 0.05$, the maximum error in the position of the soundings was about 60 meters, that is, 0.2 mm. on a scale of 1 : 250.000, which was the scale on which the survey was made.

The aligments were spaced at 2.500 meters, this being the distance used for the soundings on each alignment. They ran from east to west and extended off-shore to the point where the 700 metre bathymetric line was reached.

The work already accomplished has shown up various characteristics of the Bank. Its gradient is very gentle, but the submarine relief is most irregular, particularly between Bazarute and Chiloane Islands. It is distinguished by the presence of large dunes, more or less symmetrical in section, which show considerable level differences similar to those found in the North Sea (« Sand Undulations in the North Sea », Joh. Van Veen, *H. R.*, No. 23, May, 1935).

A certain number of shoals of interest to navigation were located during the soundings and their positions were reported to the appropriate services. In comparing this new information with earlier reports made, it was found that some of the shoals met with are new, while others reported earlier were not encountered.


Delta do rio Zambéze
Batimétrica dos 20m
Batimétrica dos 100m
BEIRA
SOFALA
BANCO
DE
SOFALA
ESCALA

The Mozambique Hydrographic Survey is continuing with its work and it is anticipated that the survey of the Sofala Bank will be completed in about two years. The chart of the area already drawn, which will be published very soon, is not only a contribution towards a greater scientific understanding of the continental shelf and towards a greater maritime navigational safety in these parts, but is also an example of the considerable help that radio-electric methods offer towards the solution of difficult hydrographic problems.