Multibeam Line Design Based on Geometric Analysis

Qin Liao [1, *], Hong Xiao [2], Guijie Xiao [3]

[1] School of Economics and Management, Jiangxi University of Science and Technology
Ganzhou, China, 341000

[2] School of Information Engineering, Jiangxi University of Science and Technology
Ganzhou, China, 341000

[3] School of Civil Engineering and Eurveying and Mapping Engineering, Jiangxi University of Science and Technology, Ganzhou, China, 341000

* Corresponding Author Email: dellliao@outlook.com

Abstract. Multibeam bathymetry is a bathymetry technique of wide sector propagation and strip coverage by simultaneously transmitting and simultaneously receiving multiple beams. This paper mainly focuses on the problem of multibeam transmitting, combines theoretical proofs and data laws, respectively conducts qualitative analysis and quantitative analysis of the survey line layout scheme, and concludes that in the case of the shortest total length of the survey line, all the survey lines are straight lines parallel to each other, and the angle of the direction of the survey line is 90°, and the coverage rate between any neighboring strips is 10%. The total length of survey lines is modeled by geometric analysis, and the optimal survey line deployment scheme contains 34 survey lines, with a total length of 125936 m. The optimal survey line deployment scheme is based on the model of the total length of survey lines.

Keywords: Multibeam bathymetry; Line placement; Geometric analysis.

1. Introduction

With the rapid progress of digital technology, the development and utilization of the ocean by all countries in the world has reached an unprecedented depth and breadth. In order to realize the comprehensiveness and accuracy of the seabed knowledge, the introduction of clear image information and accurate digital information into marine research has become the inevitable requirement of today's era [1].

Compared with single-beam bathymetry, multibeam bathymetry system has the advantages of large measurement coverage, fast measurement speed, high accuracy and efficiency [2], and it can measure a full-coverage bathymetry strip with a certain width on the axis of the survey line of the survey ship in a flat sea area.

Multibeam bathymetric system is developed on the basis of single-beam bathymetry, the system in the plane perpendicular to the trajectory at the same time to the seafloor tens or even hundreds of beams, the measuring ship transducer sends out the acoustic wave to reach the seafloor, and then by the receiving transducer to receive, the system can be recorded from the acoustic wave emission to the signal received by the transmission time, through the acoustic wave propagation speed in the seawater and the time of propagation of seawater can be calculated. Depth.

Based on the above background analysis and known conditions, it is necessary to establish a model to complete the following problem:

Consider designing a set of measurement lines with the shortest measurement length that can completely cover the entire sea area to be measured in a rectangular sea area with clear boundaries, and the overlap rate between neighboring strips meets the requirement of 10%~20%.

2. Research Methods

To design a set of survey lines with the shortest measurement length, which can completely cover the whole sea area to be measured, and the overlap rate between neighboring strips meets the requirement of 10%~20%. With regard to the length and width, orientation and slope of the sea area to be measured, it is analyzed that there may be a certain angle of measurement line direction, so that the total length of the line is the shortest in the case of covering the whole sea area to be measured, and the optimal angle of measurement line direction can be sought from the theoretical method and the quantitative method of the data, and finally the optimal measurement line deployment scheme is taken as the optimal measurement line, and the mathematical model of the total length of the line is established for solving the corresponding results.

3. Modeling and solving

3.1. Theoretical level qualitative proof of the shortest survey line design

For multibeam bathymetry operations in the sea area to be measured, the survey line design should be carried out before the survey, according to the characteristics and requirements of the area to be measured, and scientifically and reasonably lay out the planned survey line [3-5]. According to the decision-making objectives and constraints, the survey line design parameters can be analyzed theoretically.

The transducer transmitter beam is projected onto the seafloor slope, and the strip coverage width of neighboring survey lines needs to have at least 10% of mutual overlap area, in order to avoid generating the detection blind zone and ensure the completeness and accuracy of the measurement data. In the clear area to be measured in the sea, the overlap rate needs to be taken in the range of 10% to 20%, the higher the overlap rate means that the denser the distribution of the measurement line, the larger the total length of the measurement line in the fixed range to be measured, this paper considers that the overlap rate of the neighboring strips should be determined as 10%, and the neighboring measurement lines must be parallel[6-8].

Because the layout plan of the survey line does not require that the navigation route of the survey ship is continuous, the survey line can be arranged in sections in the sea area to be measured, so it is necessary to solve the problems of the linear, Angle and positioning of the survey line.

Let the covering area of the strip corresponding to the measuring line of unit length be k_m, and the average effective area covered by the strip corresponding to the measuring line of unit length be k, where k is the ratio of the effective area to the total length of the measuring line. Effective area m1 is the area covered by its horizontal projection in the horizontal projection rectangle of the sea slope, and invalid area m_2 is the area covered by its horizontal projection in the horizontal projection rectangle of the sea slope [9,10].

3.1.1 Determination of line type

It can be seen from the differential that when the covering width is the same, when the length is the same, the covering area m of any non-overlapping lines is the same.

(1) The covered area m of the curve is composed of effective area m1 and ineffective area m_2, and the average effective area covered by the measuring line of the unit length is k1.

(2) The average effective area covered by a line that is not parallel to a rectangular edge is k_2. The covering area m is composed of effective area m1 and invalid area m_2.

(3) The line with parallel rectangular edge is the covering area m is the effective area m_1, and the average effective area covered by the measuring line with the unit length is k3.

Figure 1 shows the layout of three types of survey lines when the sea slope is flat. From the above analysis, it can be seen that $k_1<k_3$, $k_2<k_3$, linear line should be selected, and the straight line should be parallel to the side of the rectangle, $k_3=k_m$.

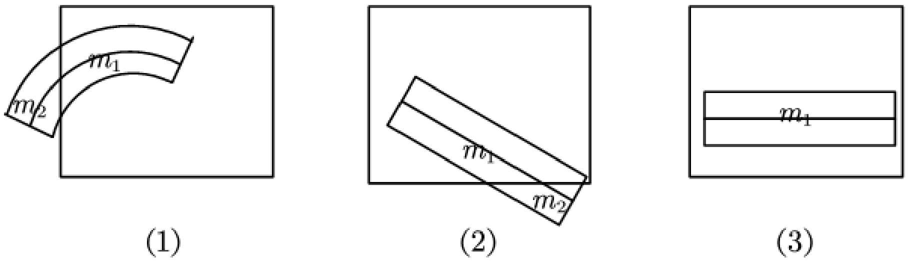

Figure 1. Layout of survey lines when the sea slope is flat.

3.1.2 Determine the position relationship of the measuring line.

Figure 2 shows the perpendicularity and parallelism of a straight line.

(1) Assuming that the lines may intersect (horizontal and vertical lines intersect), there is an overlapping area between the two strips, and the area of this overlapping area is the invalid area k will be reduced.

(2) When the measuring lines are parallel to each other, the covering area m is the effective area m1.

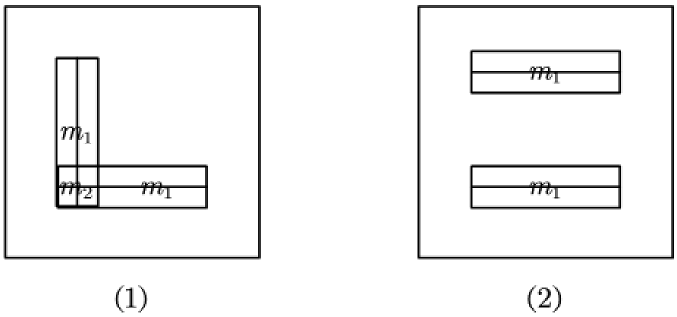

Figure 2. Vertical and parallel cases of linear lines

3.1.3 Determination of measuring line spacing

Considering the slope inclination, it is assumed that the strip cover width is proportional to the water depth (Figure 3).

(1) When the distance is equal, the change in the water depth will cause the change in the strip cover width, which will increase the strip overlap rate in the deep water, increase the ineffective area m2 and decrease k.

(2) When the spacing is not equal, the increase of invalid area m2 can be reduced by changing the distance of adjacent strips due to the increase of strip overlap rate.

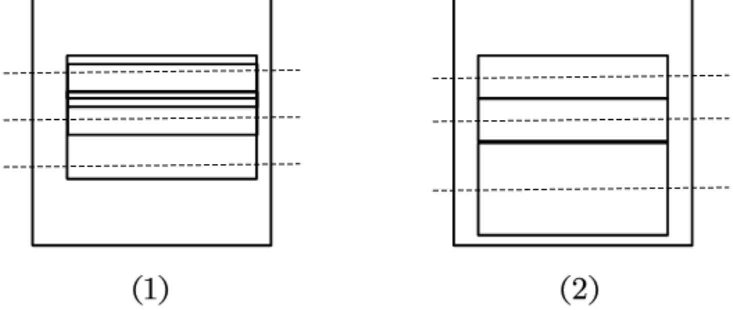

Figure 3. Distance distribution between adjacent measurement lines.

3.1.4 Determination of straight-line Angle (considering the slope inclination)

It can be seen from Figure 4. (1) that the straight line should be selected parallel to the rectangular edge, and there are two kinds of straight lines when it is tilted:

(1) Perpendicular to the isobath, the change of the water depth will cause the change of the cover width of the strip, and the strip is trapezoidal. At the boundary, in order to meet the requirement of no leakage measurement, part of the cover area will exceed the rectangle, resulting in invalid area.

(2) Parallel to the isobath, the strip is rectangular at this time, and no invalid area will be generated.

From the above analysis, it can be seen that the layout scheme of the survey line with the shortest measurement length should be parallel to the isobath line, parallel to each other, unequal spacing and discontinuous lines.

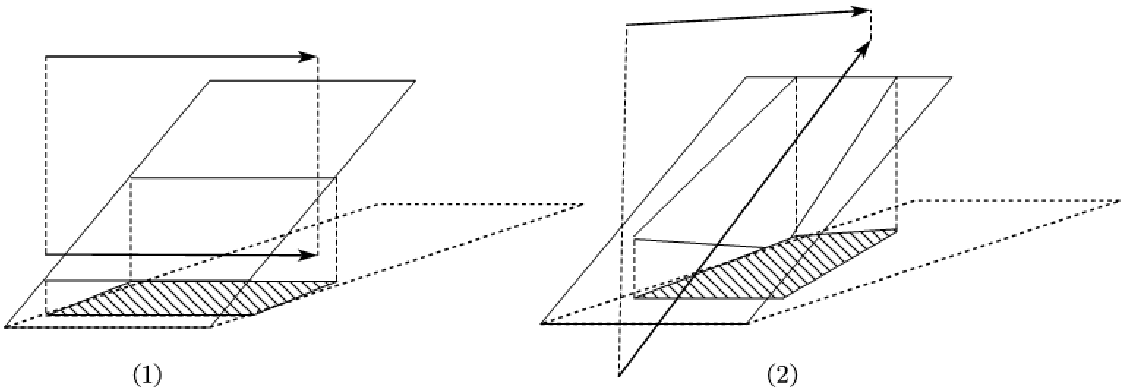

Figure 4. Considering the layout of the survey line of the slope slope

3.2. In terms of data, the design of the shortest measurement line was quantitatively derived

In order to explore the relationship between the direction Angle of the line and the total length of the line, the following mathematical model is established to determine the shortest direction Angle of the total length of the line. For any rectangular plane with known boundaries, to achieve complete coverage of the entire area in the form of a strip, you can start from the vertex at the bottom of the rectangle, and gradually parallel route to the top of the rectangle with a certain line spacing until the strip coverage width exceeds the entire area to be measured.

The Angle between the measurement line direction and the positive direction of the X axis is φ, l_1 is the north-south length of the sea area to be measured, l_2 is the east-west width of the sea area to be measured, K is the number of measurement line spacing, and D is the measurement line spacing.

Case 1:0°≤φ<90°. Figure 5 shows the geometric relationship diagram of Case 1.

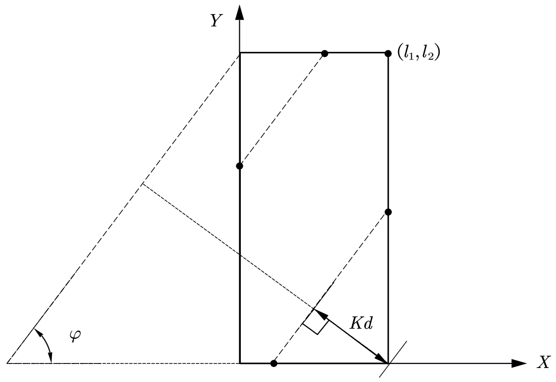

Figure 5. Schematic diagram of case 1 geometric relationship

According to the Angle between the direction of the measurement line and the positive direction of the X axis φ, the equation of the measurement line in case 1 can be determined:

$$y_1 = \tan\varphi(x - (l_1 - \frac{Kd}{\sin\alpha})) \tag{1}$$

Case 2:90°<φ<180°. Figure 6 shows a schematic diagram of the geometric relationship in case 2.

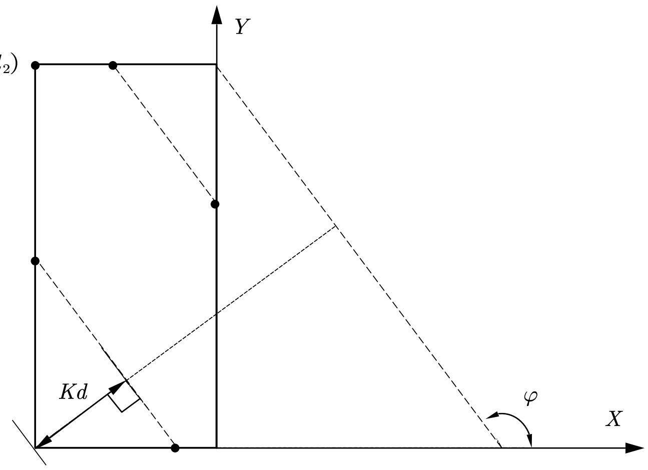

Figure 6. Schematic diagram of the geometric relationship in case two

Equation of measuring line in case 2: $y_2 = \tan\varphi(x - \frac{KD}{\sin\varphi})$ (2)

Case 3: φ=90°

Equation of measurement line in case 3:

$$x = C, \left(C \in \left(0, 2\right)\right) \tag{3}$$

First of all, it is determined that the distance between the measuring line is 50m, and the Angle between the measuring line direction and the positive direction of the X axis is φ in ├ 0,180^∘) with a step of 1° to traverse the total length of the measuring line with φ changes as shown in Figure 7.

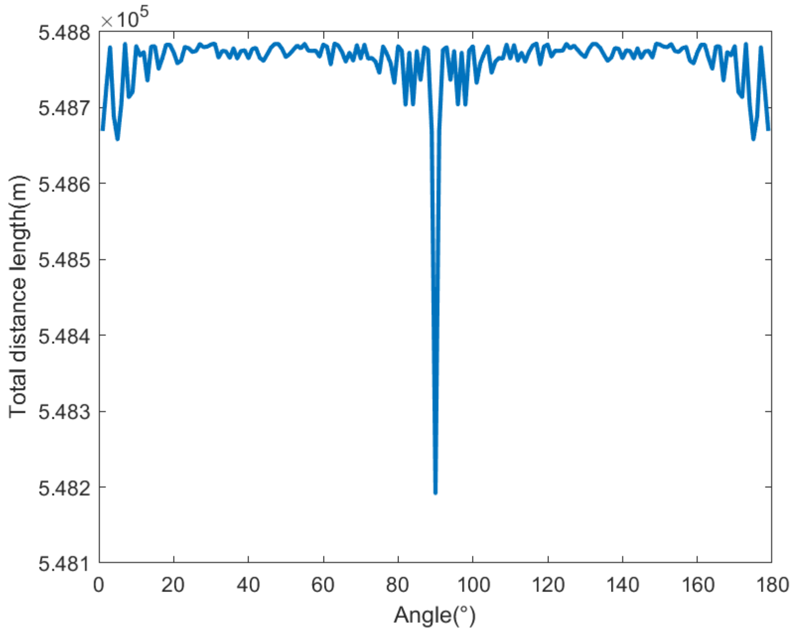

Figure 7. Schematic diagram of the total length of the measuring line as a result

By observing the diagram of the above results, it is found that the total length of the measured line is the shortest when φ=90°. At the same time, on the basis of Figure 7, the spacing of measuring lines is traversed, and the change diagram of the total length of measuring lines with φ and d is shown in Figure 8.

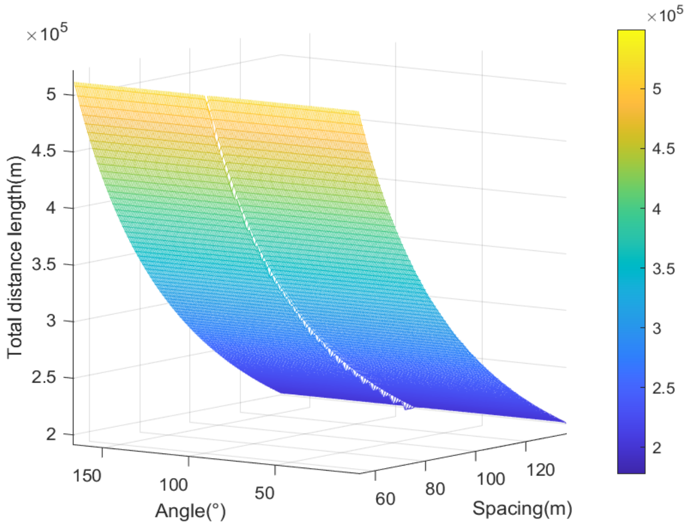

Figure 8. Schematic diagram of the total length of measuring line with φ and d

By observing the schematic diagram of the above results, it is found that the total length of the survey line is the shortest when φ=90° in any given distance of the survey line. It is concluded that the total length of the survey line is the smallest when the Angle between the direction of the survey line and the contour of the slope is 90°.

3.3. Establishment of the total length model of measuring line

According to the above proof process, when the Angle β of the survey line direction is 90°, the total length of the survey line is minimum, the projection of the survey line direction and the normal direction of the submarine slope on the horizontal plane is perpendicular to each other, the strip coverage width is the same in any vertical section of the same survey line, and each survey line is parallel to each other, and the design of the survey line spacing can be carried out according to the coverage rate of the strip formed by the adjacent survey line. Until the strip width of all survey lines can completely cover the entire sea area to be measured. The relevant characteristic quantity at the first measurement line can be determined by laying the measurement line from the intersection line between the slope area to be measured and the seabed plane and making the strip width boundary of the first measurement line coincide with the intersection line. d is the distance between two adjacent survey lines, α is the slope of the submarine slope, and D_1 is the depth of the sea water at the location of the first survey line. The geometric model of the total length of the measured line is shown in Figure 9.

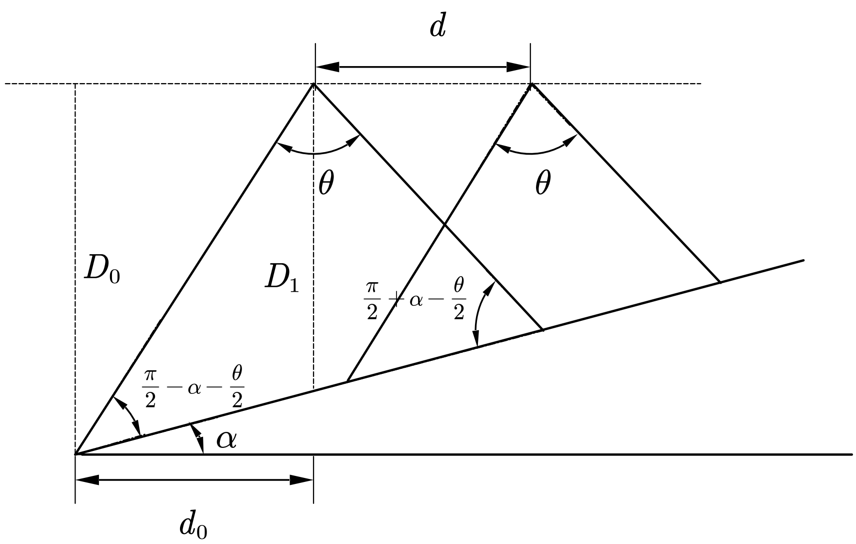

Figure 9. Three-dimensional diagram of the coverage width

The depth of the sea water at the location of the intersection line between the measured slope area and the seabed plane is D_0:

$$D_0 = D_1 + d_0 \tan\alpha \tag{4}$$

In the triangular section where the transducer transmits multiple beams, the sine theorem can be used to obtain:

$$\frac{d_0 / \cos\alpha}{\sin\frac{\theta}{2}} = \frac{D}{\sin\left(\frac{\pi}{2} - \alpha - \frac{\theta}{2}\right)} \tag{5}$$

For the solution of each characteristic quantity between two adjacent measurement lines, change the distance between measurement lines to d_i, representing the distance between the i-measurement line and the i+1 measurement line, and make the overlap rate η between adjacent strips =10%, the following calculation formula is obtained:

$$d_i = \sin\frac{\theta}{2}\cos\alpha\left[\frac{D_{i+1}}{\sin\left(\frac{\pi}{2} - \alpha - \frac{\theta}{2}\right)} - \frac{10\% \times D_i}{\sin\left(\frac{\pi}{2} - \alpha - \frac{\theta}{2}\right)} + \frac{90\% \times D_i}{\sin\left(\frac{\pi}{2} + \alpha - \frac{\theta}{2}\right)}\right] \tag{6}$$

According to the requirement that the strip width can completely cover the entire sea area to be measured, the sum of the total length of the spacing of all adjacent survey lines and the distance from the first survey line along the slope to the seabed should be greater than or equal to the east-west width of the sea area to be measured L_2, and the number of survey lines n is the minimum survey line number satisfying this condition. The calculation formula is as follows:

$$\sum d_i + d_0 \geq L_2 \tag{7}$$

When the direction Angle of the measurement line is 90°, the length of each measurement line in the rectangular area to be measured is the north-south length L_1 of the sea area to be measured, and the total length of the measurement line L is:

$$L = n\,L_1 \tag{8}$$

3.4. Model solution

On the basis that the layout scheme of the line satisfies all constraints, according to the above design scheme of the line with the shortest measurement length, it is proved that the layout scheme of parallel line with the Angle of 90° in the direction of the line is selected as the optimal scheme, and the total length model of the line is used to substitute the known data for solution.

A total of 34 lines were obtained, and the total length of the lines was 125936 m. The location of the survey line is represented by the distance between the survey line and the westernmost side of the submarine slope, and the strip distribution diagram of the submarine slope is shown in Figure 10.

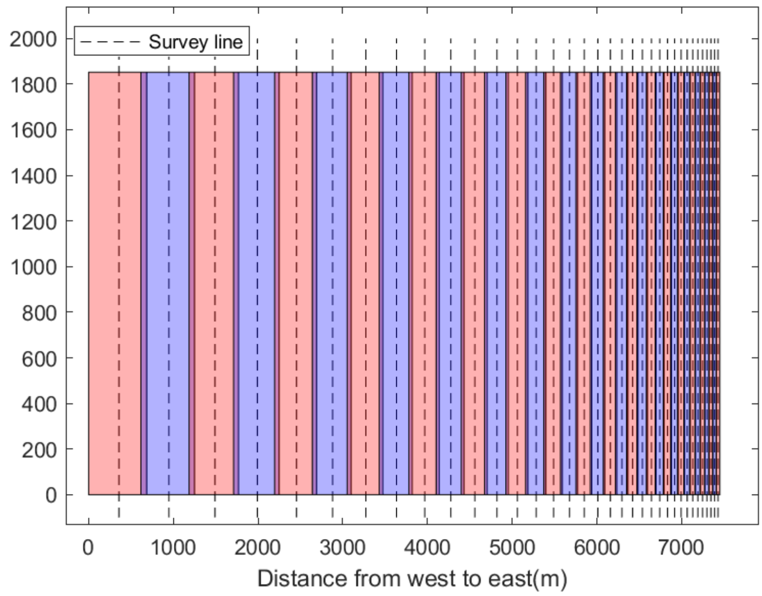

Figure 10. Schematic diagram of strip distribution of submarine slope

Multi-beam sounding was carried out in the sea area to be measured with deep west and shallow east, and the overlap rate between adjacent strips was 10%, forming the strip distribution as shown in Figure 8. The sea water in the west side was deeper and the strip coverage width was wider, so the survey lines were sparse. The depth of sea water in the east side is shallow, and the width of strip coverage is narrow, so the survey line is dense. Because the direction of the survey line is perpendicular to the projection of the normal direction of the submarine slope on the horizontal plane, the depth and strip width of the sea water corresponding to the same survey line are the same.

4. Conclusions

In this paper, the transmitting problem in multi-beam sounding technology is deeply studied and analyzed, and an optimized line layout scheme is proposed. Through qualitative and quantitative analysis, this paper proves that under the premise of ensuring the shortest total length of the survey lines, all the survey lines should be arranged as parallel lines, and the direction Angle of the survey lines is 90°, so as to ensure that the coverage rate between any adjacent strips is constant 10%. This scheme not only improves the efficiency and accuracy of the measurement, but also establishes a total length model of the line through geometric analysis, which can guide the practical multi-beam sounding operation.

Further, this paper obtains the optimal survey line layout scheme through the model calculation, which includes 34 survey lines with a total length of 125936 meters. This result provides important theoretical basis and practical guidance for the practical application of multi-beam sounding technology and has important reference value for the research of Marine geology, ocean engineering and other fields. In addition, this study also reveals some key data rules in multi-beam sounding, which provides a solid foundation for future related research.

In summary, the research results of this paper not only improve the operational efficiency and data quality of multi-beam sounding technology, but also provide a new perspective and method for research in related fields. In the future, with the continuous development and improvement of multi-beam sounding technology, the research results of this paper are expected to be more widely used in the field of Marine science and technology.

References

[1] Wilson M F J, O'Connell B, Brown C, et al. Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope[J]. Marine Geodesy, 2007, 30(1-2): 3-35.

[2] Pike, S.; Traganos, D.; Poursanidis, D.; Williams, J.; Medcalf, K.; Reinartz, P.; Chrysoulakis, N. Leveraging Commercial High-Resolution Multispectral Satellite and Multibeam Sonar Data to Estimate Bathymetry: The Case Study of the Caribbean Sea. Remote Sens. 2019, 11, 1830.

[3] Wölfl, A.-C.; Snaith, H.; Amirebrahimi, S.; Devey, C.W.; Dorschel, B.; Ferrini, V.; Huvenne, V.A.I.; Jakobsson, M.; Jencks, J.; Johnston, G.; et al. Seafloor Mapping—The Challenge of a Truly Global Ocean Bathymetry. Front. Mar. Sci. 2019, 6, 283.

[4] Dudkov I, Dorokhova E. Multibeam bathymetry data of Discovery Gap in the eastern North Atlantic[J]. Data in brief, 2020, 31: 105679.

[5] Pillay T, Cawthra H C, Lombard A T. Characterisation of seafloor substrate using advanced processing of multibeam bathymetry, backscatter, and sidescan sonar in Table Bay, South Africa[J]. Marine Geology, 2020, 429: 106332.

[6] Bongiovanni C, Stewart H A, Jamieson A J. High-resolution multibeam sonar bathymetry of the deepest place in each ocean[J]. 2022.

[7] Cui X, Liu H, Fan M, et al. Seafloor habitat mapping using multibeam bathymetric and backscatter intensity multi-features SVM classification framework[J]. Applied Acoustics, 2021, 174: 107728.

[8] Guo Q, Fu C, Chen Y, et al. Application of multi-beam bathymetry system in shallow water area[C]//Journal of Physics: Conference Series. IOP Publishing, 2023, 2428(1): 012042.

[9] Wanda T F, Wiles E A, Cawthra H C, et al. The value of multibeam bathymetry in marine spatial planning in South Africa: A review[J]. South African Journal of Science, 2023, 119(9-10): 1-7.

[10] Ou X, Zhu J, Li S, et al. Submarine geomorphological features and their origins analyzed from multibeam bathymetry data in the South China Sea[J]. Journal of Marine Science and Engineering, 2021, 9(12): 1419.