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Study on the Soundings Arrangement of Seafloor Topography Representation Model

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Abstract. The representation method for submarine topography is mainly the sounding notations combined with depth contours representation currently, and the sounding notation is the important part of the seabed terrain representation model. The most commonly intuitive and used seabed terrain representation model is the chart. The users understand the sea area through the interpretation of depth notation in chart, which contribute to achieve safe navigation and well-off exploitation. The density of bathymetric notation is specified in various regulations on charting that proposed by the state, thus the arrangement of soundings is only mentioned simply without stating any reason. Based on the characteristics of seabed topography and the features of hydrographic survey, the conditions that the soundings arrangement should satisfied are analysed, two types of soundings notation places which can meet the conditions are induced. Finally, the two arrangements are compared on the representation ability, and accuracy and feasibility of the rhombohedral arrangement are verified better by the results of the statistical calculation.

1. Introduction

The seafloor topography is complex and varied，the same as the land topography. However, it is covered by water, so it can only be understood through the representation model of the seafloor topography. The chart is one of the most basically, commonly and intuitively seabed terrain representation model. Mankind need chart help them get the information about the seabed terrain whether on maritime navigation or marine exploitation. The chart is made up of oceanic and terrestrial elements, meanwhile the sounding notation and depth contours play important roles in oceanic elements. The users can obtain the understanding of the water area through the interpretation of the sounding notation and isobath in the chart, so it can help navigate and exploit safely and smoothly. The chart sounding notations are mainly derived from the final results of the bathymetric measurements, and the function is to express the seafloor situation accurately. The density of sounding notation has been stipulated in detail in various specifications for making chart, but the arrangement of sounding notation is only mentioned simply:” The sounding notation should be arranged in the shape of a diamond.” However, no explanations are given. Obviously, there can be a variety of patterns under the condition of the same sounding density. The requirements that sounding notation arrangement should meet are analysed, based on the changing rules of the submarine topography and hydrographic methods. Consequently, there are two qualified forms chosen from many arrangement types. One is the diamond array, which recommended by specifications. Which one is better? In this paper, the smoothness effect is introduced as an index to analyse and discuss the two forms in terms of the ability to represent the seafloor topography. At last, the differences are calculated and compared by some examples. In the calculation, the sounding for the middle of three measured lines is taken as the true value, and the limit error of depth measurement proposed in the *Specifications for Hydrographic Survey* (hereinafter referred to as the *Specifications*) is used as the accuracy standard for estimating data.

2. Selection features and arrangement forms of soundings notation

2.1 Soundings density characteristics

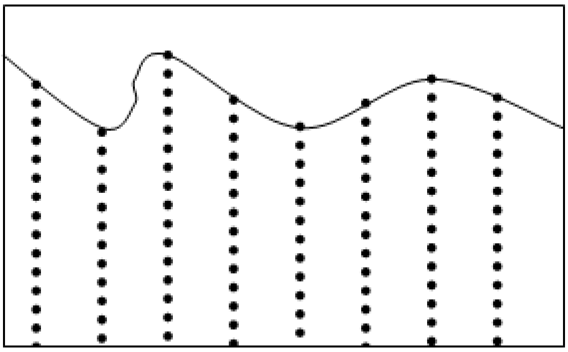

Fig. 1. A sounding board.

Depth of notes is an important part of the chart, it mainly comes from hydrographic measurement which is mainly for getting water depth. The surveying results are handled to become a sounding board (see Fig. 1). According to the relevant provisions of the *Specifications*, the density of sounding notations in the sounding board is considerable, and the map scale is generally big. As a result, there would be a chart with sizable sounding notations density when all the measured data are converted to the mapping scale. Nevertheless, is the denser the soundings the better? Practice has proved that this is not the case. Although all measured water depth expressed can guarantee the safety, the excessively dense soundings figures will also directly affect the applying effects of the chart. If the data volume is too large, it will bring great inconvenience to the seafarers. When the navigator faced with a chart full of figures, he or she even is difficult to find a rock in it. How can he or she clearly and accurately judge the topography of the sea area? Therefore, it is necessary to select and delete soundings when make the chart. Finally, the density of bathymetric notation is in accordance with the relevant provisions in the norms for charting proposed by the state, as shown in table 1 and the following text.

Table.1.The density of soundings

Depth range (m)	0~20	20~50	>50
Note spacing(mm)	10~15	12~20	18~30

In addition, the density can be properly increased in the fluctuating seafloor topography areas, meanwhile, the density of flat sea area can be appropriately reduced. Watercourse, navigation gate, complex sea area, turning point of customary channel, anchorage, prominent headland and sea area with complex seabed topography, the spacing of water depth notes can be reduced to 8~10mm. However, on our actual bathymetric chart board, the interval between sampling points of water depth is usually 2 mm ~ 6mm, and large scales surveying is often adapted. It is obviously that there is a big gap between the actual demand and measured data, so it is very necessary to select appropriately.

2.2 The reasonable sounding selection form

In the various specifications, only the arrangement density of the water depth notes is specified, but the arrangement form of the sounding notation is simply mentioned: "the water depth arrangement should be in diamond shape" without any explanation. Under the same density, there are many possible arrangements, such as diamond (Fig. 2and Fig.3), rectangular (Fig. 4), square (Fig. 5), etc., but these forms may not all be reasonable. In this paper, the basic thought is that chart sounding notations are deprived from the results of hydrographic surveying, so that the selection and arrangement of the sounding must depend on the surveying depth lines firstly. The *Specifications* stipulates that the direction of the main sounding line should be perpendicular to the general direction of the isobath. Therefore, combined with the changing law of seabed topography and the method of hydrographic survey, this paper believes that under the premise of meeting the basic requirements of national norms, the arrangement of chart water depth notes should meet the following conditions: firstly, it can represent the seabed topography. Although the seabed topography is complex and variable and invisible, not without rules to follow, any kind of seabed topography has a certain law of slope slope change. Generally, in the direction parallel to the coast, the inclination is small, that is, the sea depth changes slowly; in the direction perpendicular to the coast, the slope is large and the water depth changes quickly. Therefore, in order to fully reflect the characteristics of the seabed topography, it is required that when using the chart representation, the water depth should be spaced sparsely in the direction parallel to the coast and closely in the direction perpendicular to the coast; Secondly, it is necessary to adapt to the method of hydrographic survey. The sounding line is usually arranged along the direction perpendicular to the isobaths. In this way, in the same survey line (that is, in the direction perpendicular to the isobath), the depth note density is large and the interval is small. However, between two adjacent survey lines (that is, in the direction parallel to the isobath), the interval between the water depth notes is large. Comprehensive the above two points, we think that is not so much on the depth of the water depth on board note, as the different forms of water depth on the sounding board note sampling, because of the volume of water depth and the depth of the water board position is the raw data, cannot be changed, so we any form of arrangement is based on its basic form, just different sampling methods, and form the different forms of arrangement.

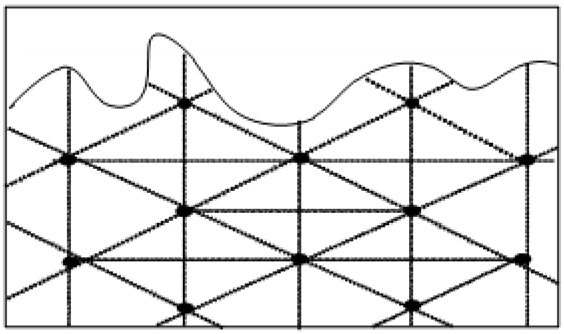

Fig.2 Diagram of diamond arrangement
（The short diagonal is perpendicular to the coast）

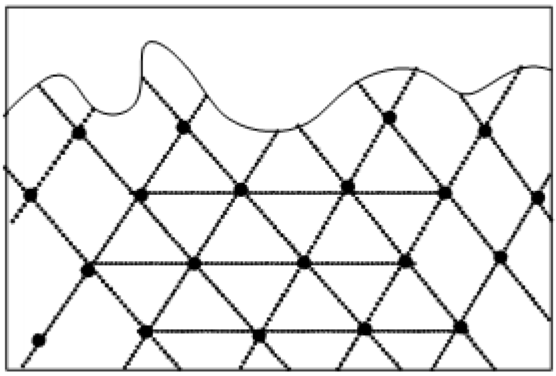

Fig.3.Diagram of diamond arrangement
The long diagonal is perpendicular to the coast

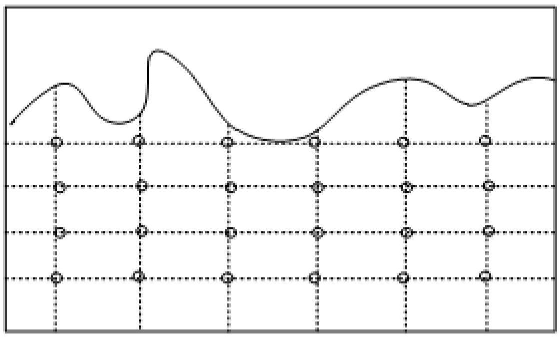

Fig.4 Diagram of rectangular arrangement

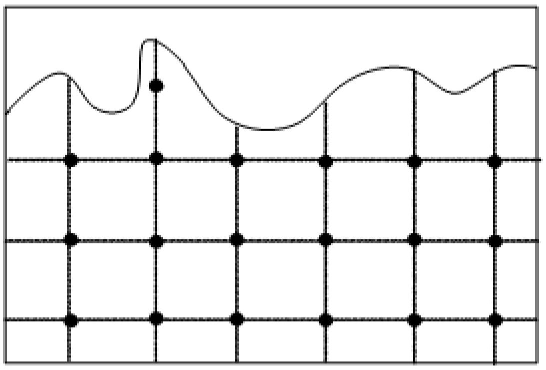

Fig. 5. Diagram of square arrangement

2.3 The reasonable choice of form

According to the above two conditions, combined with figures 2, 3, 4 and 5, it can be seen that, the rhombic and rectangular arrangement of water depth is the feasible arrangement, and the rhombic arrangement is only applicable when the short diagonal is perpendicular to the coast, while the rhombic and square arrangement of the long diagonal is not feasible.

As can be seen from figures 2 and 4, both the rhomboid arrangement (hereinafter referred to as the rhomboid arrangement) and the rectangular arrangement perpendicular to the shore of the short diagonal can meet the conditions summarized above: In the direction parallel to the coast, the sounding notation is spaced sparsely, while in the direction perpendicular to the coast, it is spaced closely. On the same measuring line (in the direction of the short diagonal of the rhombus or the short side of the rectangle), the water depth is marked with high density and small spacing. Between two adjacent gauges (in the direction of the long diagonal of the rhombus or the long side of the rectangle), the water depth mark interval is larger.

3. The comparison of rhombus and rectangle arrangement

3.1 The standard to evaluate both methods

Rhombus arrangement and rectangle arrangement can meet the requirements of water depth notation arrangement, but rhombus arrangement is recommended in national regulations. Since rhombus and rectangle are both feasible choices according to the above analysis, why choose rhombus instead of rectangle? Did not explain in the specification and related data, this article through access to relevant data and combined with the structure characteristics of the diamond, think that it is recommended to use the diamond to arrange the reason: the first is to better display the seabed morphology, meet the demand of navigation, to ensure the safety of navigation, this paper will be used later analysis calculation of verification; The second is to enhance the clarity and beauty of the chart, improve the expressive force of chart, because the diamond is made of the triangle, suitable for the construction of triangulation, and triangulation in for fitting of irregular topography is better than that of the grid, so diamond array when the note for us to use to build the DEM has provided the good condition, in addition, due to the diamond rectangle is determined by their structure characteristics, on the premise of guarantee the density conform to the standard, the same area, using diamond array can reduce negative load chart data, so as to further improve the clarity of the chart.

Now, we will use an example calculation analysis to verify whether rhombus arrangement or rectangle arrangement can more accurately represent the seabed topography. As mentioned above, in order to ensure readability, the density of water depth notes on the chart is small, and the chart reader can only obtain the water depth of the unmarked area by interpolation. It is easy to see that due to the characteristics of rectangular and rhomboid shapes, the accuracy of estimating unknown points with rhomboid arrangement is better than that with rectangular arrangement. Therefore, this paper believes that this should be the most important basis for the adoption of rhombic arrangement in water depth annotation. Therefore, this paper uses the concept of "water depth interpolation smoothing effect" and the calculation of an example to verify this idea. The "depth interpolation smoothing effect" is the difference between the interpolated depth and the measured depth. This paper uses this difference to evaluate the linearity between the notes of different arrangements in the chart, and then makes a comparative judgment on the strength of the two different arrangements for the representation of seabed topography.

3.2 The steps to compare and evaluation indicators

In the calculation, the water depth of the middle one of the three sounding lines on the bathymetric chart is first used as the truth value, and then the two adjacent sounding lines are selected as a diamond and a rectangle respectively. Then, the selected data are used to estimate the depth data at the corresponding position on the known survey line, and the results of the estimated results are compared with the measured data, so as to judge the strength of the ability of the two different arrangement methods to characterize the seabed topography. Linear interpolation method is used in the estimation calculation, which is also in line with the way of thinking of graph readers and graph users. The functional form of the bilinear interpolation method is as follows: $z = a_0 + a_1x + a_2y + a_3xy$, four parameters of which can be obtained according to the four known reference points adjacent to the interpolation point, and then the coordinate of the interpolation point is used to get the water depth value (Li Zhilin, 2001).Numerical calculation process using Visual C++ language programming.

Then, some mathematical indexes are used to evaluate the calculation results of smoothing effect. Since the bathymetric data in the chart are derived from the bathymetric measurement results, and there is no corresponding provision for the error of bathymetric value in the relevant specifications,

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therefore, the limit error of depth measurement in the code is used to evaluate the linearity between notes of different arrangement forms in the chart, and finally to make a comparative judgment on the strength of the two different arrangements for the representation of seabed topography.

The following evaluation indicators were used in the study:

(1)、The mean of the difference (absolute value) $\overline{|d|}$:

$$\overline{|d|} = \frac{1}{N}\sum_{i-1}^{N}\overline{|d_i|}$$

(2)、Maximum and minimum difference (absolute value) $|d|_{max}$,$|d|_{min}$;

(3)、Range (the difference between the maximum difference and the minimum difference) Δd :

$$\Delta d = |d|_{max} - |d|_{min}$$;

(4)、 Interpolation error:

$$m = \pm\sqrt{\Sigma d^2 / N}$$

（N—The number of points taken）

The limit error of sounding in *Specifications* is shown in table 2.

Table.2.The provision for limit error in sounding

Range	Limit error
0<Z≤20	±0.3
20<Z≤30	±0.4
30<Z≤50	±0.5
50<Z≤100	±1.0
Z>100	±Z×20%

4. Example calculation and analysis

The data measured in a sea area of the east China sea is selected as an example. The terrain is divided into three regions: complex, general and flat. After statistical calculation, the data are shown in table 3~7. The rhombus or rectangle shown in the table respectively indicate that the sampling method adopted is rhombus or rectangle.

As mentioned earlier, four indicators are used in statistical calculation, but among these mathematical indicators, |d| and m reflects the overall trend of smoothing effect, both of which can reflect the overall smoothing effect. Therefore, these two indexes are taken as the main indexes to evaluate the smoothing effect, and the calculation results of these two indexes are only listed in this paper.

Table.3.The results of flat sea area (cm)

Indexes	Rectangle	Rhombus
$\overline{|d|}$	3.96	3.79
m	4.95	4.83

The results in table 3 were obtained by collecting 45 points on a bathymetric line in a flat sea area. The water depth value Z range is 21<Z<30(meters).

Table.4.The results of generic sea area (cm)

Indexes	Rectangle	Rhombus
$\overline{|d|}$	18.30	17.07
m	22.28	20.87

The results in table 4 were obtained by collecting 43 points on a bathymetric line in a general sea area. The water depth value Z range is 12<Z<36(meters).

Table.5.The results of complicated sea area (cm)

Indexes	Rectangle	Rhombus
$\overline{\lvert d \rvert}$	24.12	17.53
m	38.34	28.61

The results in table 5 were obtained by collecting 69 points on a bathymetric line in a complex sea area. The water depth value Z range is 3<Z<28(meters).

Table.6.The result in different depth scope in generic sea area (cm)

Indexes	10<Z≤20		20<Z≤30		Z>30	
	Rectangle	Rhombus	Rectangle	Rhombus	Rectangle	Rhombus
$\overline{\lvert d \rvert}$	24.57	22.39	15.05	13.89	11.90	11.84
m	29.46	26.40	17.73	16.74	14.92	14.35

Table.7.Result in different depth scope in complicated sea area (cm)

Indexes	0<Z≤20		20<Z≤30	
	Rectangle	Rhombus	Rectangle	Rhombus
|d|	23.21	16.72	27.14	20.21
Δd	147.89	133.55	85.41	70.85
m	38.99	28.62	36.09	28.60

For the convenience of comparison with the limit error of depth measurement, we further refined the data classification. According to the corresponding water depth range in table 2, continue to classify and summarize, and get table 6 and table 7. Since the water depth span of the flat sea area is small and completely corresponds to a range in table 2, only general sea area and complex sea area are further counted.

Horizontal comparison of mathematical indicators |d| and m in the above tables shows that, regardless of the sea area and depth range, the results obtained by the rhombus arrangement are smaller than the corresponding results obtained by the rectangular arrangement, that is, the accuracy of the results obtained by the rhombus arrangement is higher than that obtained by the rectangular arrangement.

After longitudinal comparison of table 3, 4, 5 and table 6 and 7, we can find that, the calculated values of |d| and m in each sea area increase successively from the flat sea area to the complex sea area. In other words, as the complexity of the sea increases, the accuracy decreases. Obviously, the more complex the terrain is, the worse the smoothness will be if the water depth is the same with the distance of the water depth. Through the comprehensive comparison between horizontal and vertical in table 3, 4 and 5, it is found that the difference between |d| and m values of rectangular arrangement and rhombic arrangement gradually increases with the increase of the degree of topographic change in the sea area.

The above analysis is obtained by horizontal or vertical comparison among the tables obtained by statistical calculation. However, in order to truly measure the smoothness effect between notes in different permutations, the statistical calculation results of |d| and m need to be compared with table 2. If it is within the limit error specified in table 2, it indicates that there is linearity among the survey lines in the sea area. After comparison, the following conclusions can be drawn: In the flat sea area, any arrangement is smooth between the notes, that is, it satisfies the linearity; In the general sea area, any arrangement is smooth between the notes, that is, it satisfies the linearity; In the complex sea area, the notes of rhombic arrangement are smooth, but the notes of rectangular arrangement are not, which is a combination of the characteristics of rectangular arrangement and the complexity of terrain.

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5. Conclusion

The analysis and calculation in this paper prove the accuracy of the rhombus arrangement in displaying the seabed topography. In addition, the rhombus arrangement can minimize the distance between four adjacent points and provide a good prerequisite for the construction of seabed DEM. On the premise of ensuring that the density meets the standard, the use of rhombus arrangement in the same area can reduce the data load of the chart, thus further improving the clarity of the chart. In terms of the visual effect of the surface, the rhombus arrangement is the most beautiful and clear one with better aesthetic effect. Therefore, the rhombus arrangement is an appropriate arrangement of water depth in the charts. But the arrangement of water depth notation is not absolute and fixed. What this paper discusses is the sea area with relative regular change of seabed inclination. Other conditions also require a case-by-case analysis.

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