Suitability Evaluation of Submarine Pipeline Layout Based on Structural Entropy Weight Method

Fuchun Yang [1], Zengliang Chang [1], Lele Li[1,*], Xingguo Gao[1], Hui Cheng[2]

[1]Shandong Electric Power Engineering Consulting Institute Corp,LTD, Jinan, 250100, China;
[2]College of Geodesy and Geomatics, Shandong University of Science and Technology, Qingdao, 266590, China

*lilele@sdepci.com

Abstract. With the gradual development of marine oil and gas resources in China, submarine pipelines play an increasingly important role in the development of marine oil and gas resources. Although the conveying process is similar to that of onshore pipelines, the construction of pipelines is greatly affected by the factors of the marine environment, such as the water depth, waves, and submarine topography, making the construction method of submarine pipelines very different from that of onshore pipeline projects. Therefore, it is especially important to evaluate the suitability of routing area planning for submarine pipeline projects. Based on the structural entropy weight method, this paper selects six evaluation factors from five aspects: seabed surface characteristics, layout conditions, geological environment, sea conflict and marine natural environment, and constructs the suitability distribution map of submarine pipeline layout. The suitability evaluation of submarine pipeline layout in Guangdong Province provides an idea for the development of marine oil and gas industry in Guangdong Province and the route planning of submarine pipeline layout.

Keywords: structural entropy weight method; submarine pipeline; suitability analysis; route planning.

1   Introduction

Submarine pipeline is an important part of offshore oil and gas development system, known as the lifeline of offshore oil and gas fields [1,2]. As the global oil and gas industry marches into the ocean, oil and gas pipelines laid on the seabed have increasingly become an important part of the global energy transportation artery. Offshore pipelines include submarine oil and gas gathering and transportation pipelines, trunk pipelines and auxiliary pressurization platforms, as well as the main pipes connected to the platforms. Its transportation process is the same as that of onshore pipelines, but because the offshore pipeline project is carried out in the sea area, the construction method is different from that of the onshore pipeline line project.

The construction of submarine pipelines is greatly affected by environmental conditions such as waves, rivers, winds and on-site conditions. It has now entered an open

sea area. The influence of hydrology and sea conditions on pipeline laying is also constantly changing. The construction of pipelines is also more and more difficult, and the influencing factors tend to be complex. Therefore, it is very important to analyze the suitability of the layout area of submarine pipeline project.

Weight calculation is the key link of suitability evaluation. At present, the commonly used weight calculation methods include analytic hierarchy process, structural entropy weight method, characteristic weight method, consistency index method, feature reversal method and so on. In this paper, the structural entropy weight method is combined with the weight calculation, which can reduce the influence of subjective evaluation to a certain extent and improve the scientific rationality of suitability evaluation.

2   METHODS AND MATERIALS

2.1   Study Area

The research area of this paper is the sea area of Guangdong Province, which faces the South China Sea. It is the most economically developed area closest to the South China Sea and the bridgehead of China 's management of the South China Sea. At the same time, Guangdong Province has superior geographical conditions, ' three sides surrounded by mountains, three rivers converge ', with a long coastline, a good port group, a broad sea surface, a relatively small degree of undulation of the marine terrain, rich oil and gas reserves, suitable for submarine pipeline layout. Therefore, from the perspective of social environment and natural environment, it is necessary to study the suitability of submarine pipeline layout. According to the actual situation of offshore oil and gas development in Guangdong Province, this paper analyzes the suitability of submarine pipeline layout in the study area from 109 ° 24 ′ E to 117 ° 05 ′ E, 19 ° 22 ′ 18 ″ N to 23 ° 04 ′ N as shown in Fig1.
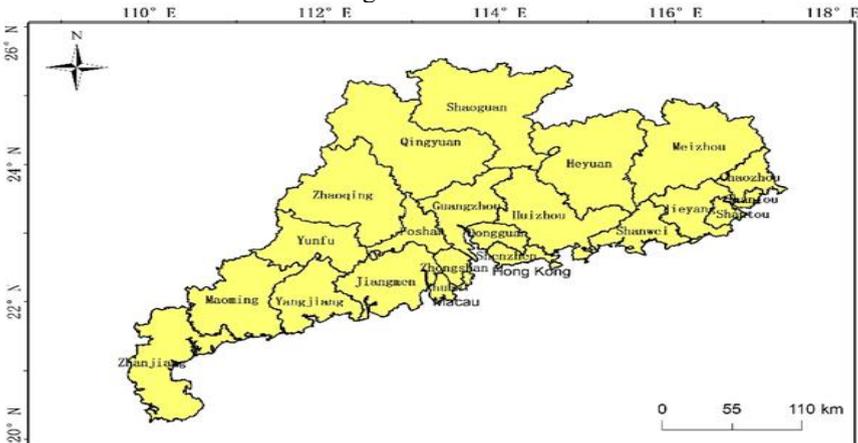

Fig. 1. Caption of a typical figure.

2.2   The selection of evaluation index

According to the actual situation of the sea area of Guangdong Province and the development and utilization of marine oil and gas resources, this paper strictly follows the principles of dominance and comprehensiveness, pertinence and contrast, applicability and feasibility of index selection, that is, the opinions of experts in the field of submarine pipeline layout are integrated. Referring to relevant research literature, the suitability evaluation of submarine pipeline layout in the study area is carried out from five perspectives: seabed surface characteristics, layout conditions, geological environment, sea conflict and marine natural environment. The following is an introduction to the selected indicators.

(1) Sediment type

The layout of submarine pipelines is attached to the surface of the seabed. According to the actual situation of the study area, the seabed in the study area mainly has the following types of sediment, coral, shell, rock, sand and mud. Different sediment types will have many effects on the stability of the pipeline and the later operation after the pipeline is laid, so the sediment type is selected as the research index.

(2) Water depth

The biggest difference between submarine pipeline layout and land pipeline layout is the difference of environment. With the increase of seawater depth in the ocean, the pressure on the pipeline increases continuously, and the corrosion degree of seawater to the pipeline will be different. Therefore, the seawater depth has a great influence on the actual construction situation when the submarine pipeline is laid. In this project, water depth is selected as an index to evaluate the development difficulty of submarine pipeline layout project.

(3) Seabed slope

The seabed topography is complex and changeable. The seabed topography in the study area is relatively flat as a whole. The slope changes slowly from north to south and steeply from east to west. The pipeline layout should be arranged according to the slope direction of the field situation. Therefore, the slope is selected as the research index.

(4) Sea conflict

While laying submarine pipelines, the original way of using the sea in the layout area should be considered. The layout of submarine pipelines will have many impacts on marine geography and ecological environment, which may conflict with the original marine utilization methods and affect marine traffic and marine economy. Therefore, this paper will be based on the sea in the study area.

(5) Marine natural environment

The layout of submarine pipelines is a large-scale offshore operation project, and the construction is affected by the marine environment. Therefore, this paper selects the ocean wave height and sea surface wind speed as the most evaluation indicators.

2.3   Data processing

Before the construction of the suitability analysis map of submarine pipeline layout, the relevant data should be processed, mainly involving the following data layers: the water depth layer of the study area, the seabed sediment layer of the study area, the sea area ownership layer of the study area, and the seabed slope layer of the study area.

In this paper, the water depth point data and the seabed sediment point data are interpolated to obtain the TIF data of the water depth and the vector data of the seabed sediment. Through the professional GIS software, the rasterization processing is carried out, and the hierarchical color display is carried out to obtain the water depth layer and the seabed sediment layer in the study area. In view of the sea area ownership data in the study area, buffer processing is carried out on the submarine pipeline data for submarine engineering during data processing, and a 100 m buffer zone is established on both sides. The area ownership data and the linear ownership data are superimposed to obtain the sea area ownership layer. In this paper, the slope layer of the study area is obtained by extracting the slope of the water depth ITF data. In this paper, the wind speed and wave height point data are interpolated and rasterized to obtain the wind speed and wave height layers in the study area. The final data processing results are shown in the plane distribution map of each index following Figure 2-7.
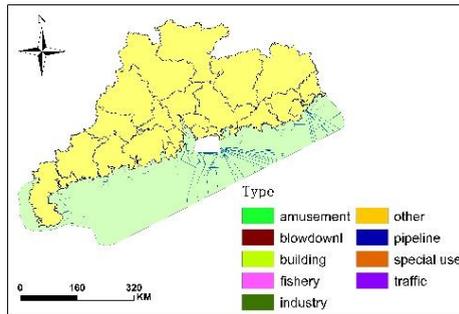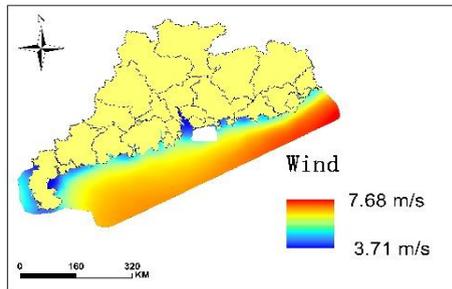

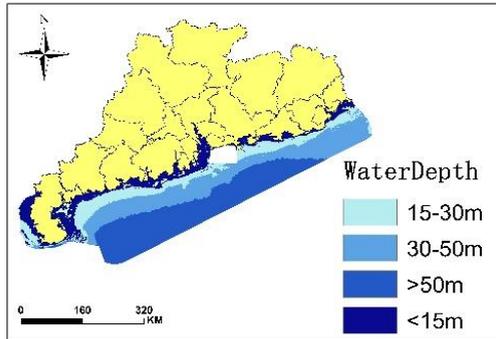
Fig. 2. Activities

Fig. 3. Wind speed

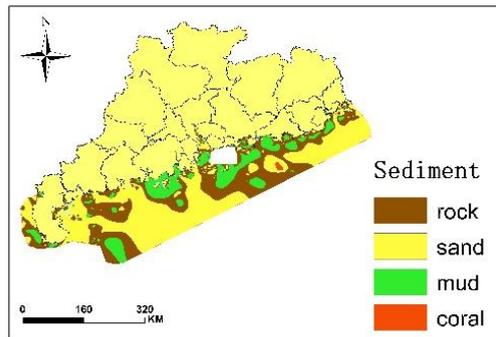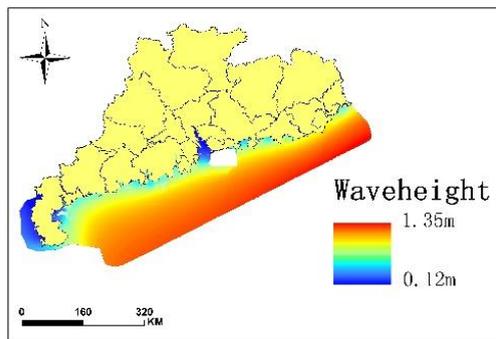**Fig. 4.** Water depth

Fig. 5. Sediment

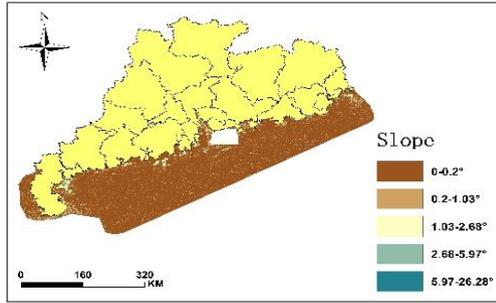**Fig. 6.** Wave height

Fig. 7. Slope

2.4   Weight calculation

The structural entropy weight method is a more objective evaluation index weighting method[3,4]. It quantitatively analyzes the uncertainty of subjective evaluation, calculates the entropy value and analyzes the blindness, so as to obtain the weight of each index. According to the evaluation set system, the opinions of 6 first-level indicators were investigated, and the statistical results of ' typical sorting ' were obtained.

In order to eliminate the differences in the ranking of the same index by different experts, it is necessary to analyze the blindness of the typical ranking table. The entropy weight method in information theory is used to calculate the entropy value of each index, and the uncertainty of the typical ranking of experts is corrected to make the evaluation results more realistic [5,6].

According to the definition of entropy in information theory, the uncertainty caused by cognition in sorting is called 'cognitive blindness ', which is defined as:

$$Qj=max(b_{1j},b_{2j},\ldots,b_{ij})$$

Where Qj is the cognitive blindness, and the obtained X is normalized, then the weight value Wi of the index in the evaluation set μi is obtained by the following formula:

$$W_J = {X_j}\Big/{\textstyle\sum_{j=1}^{s} x_j}$$

The final expert scores and the weight distribution of each index are as table1.

Table 1. TABLE I. STRUCTURE ENTROPY WEIGHT METHOD CALCULATION RESULTS TABLE

Pipeline layout	Weigh
Sediment	0.1244
Wind Speed	0.1509
Wave height	0.1429
Slope	0.2050
Water depth	0.2815
Activities	0.0953

2.5   Overlay analysis

The weight of each evaluation index is given to the corresponding layer, and then the superposition analysis is carried out[7,8]. The sea area ownership layer, sediment type layer, seabed slope direction layer, sea water depth layer, ocean wave height layer and sea surface wind speed layer are weighted and calculated according to the following formula, and the superposition weight of each layer is obtained.

$$W_{total} = \sum_{i=1}^{n} W_i$$

After the calculation is completed according to the above formula, further superposition analysis is carried out, and the obtained suitability results are reclassified into 5 categories[9,10] according to the natural breakpoint method, that is, good suitability, good suitability, general suitability, poor suitability and poor suitability. Finally, the suitability zoning of submarine pipeline layout is obtained as Fig8.
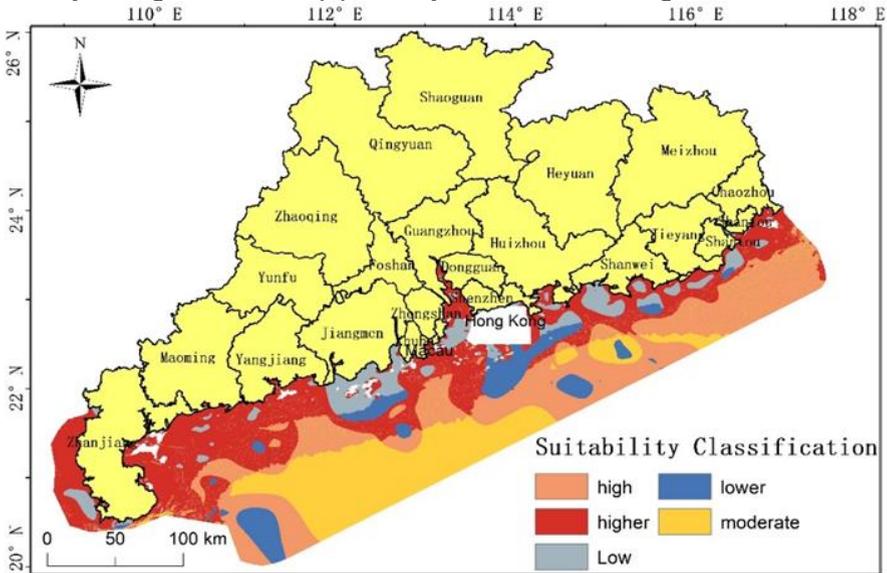

Fig. 8. Submarine pipeline layout suitability zoning map

3   RESULTS AND DISCUSSION

The suitability of the overall submarine pipeline layout in the study area is high, which is closely related to its topographic characteristics and sediment type distribution. The seabed terrain in the study area is relatively flat, and the overall slope does not change much. This is mainly affected by the topographic characteristics of the sea area of Guangdong Province. The terrain of the symbiotic sea area in Guangdong Province is dominated by plain terrain, and trenches and submarine mountains are rare. This flat terrain feature makes the layout of submarine pipelines more convenient and stable. The absence of steep terrain and dramatic slope changes can reduce the difficulty and

risk of construction, which is conducive to ensuring the safety and reliability of the pipeline.

The type of sediment also has a significant impact on the suitability of submarine pipeline layout in the study area[11,12]. According to the survey data, the overall regional suitability of the rock sediment type is higher than that of other sediment types. The rock bottom is relatively hard, which can provide stable bearing capacity to support the layout of pipelines and reduce the risk of displacement or damage of pipelines affected by external forces. In contrast, other types of sediment, such as sediment and gravel, are often relatively unstable, and more protective measures and reinforcement work need to be taken.

In addition, the suitability of the study area gradually decreases with the increase of offshore distance, which is related to the change of water depth. With the increase of offshore distance, the water depth gradually deepens, and the requirements for pipeline layout also increase. Deeper waters will increase the difficulty of pipeline construction and engineering costs, and increase the risks and challenges of pipeline operation and maintenance. Therefore, when choosing to lay submarine pipelines, it is necessary to comprehensively consider the impact of water depth changes on pipeline layout and operation and maintenance.

In the offshore area, the areas with good suitability are relatively scattered, and are often used for various marine activities and sea use methods. For example, offshore areas may involve waterways, ports, fishing grounds, etc. These uses may limit the scope and feasibility of pipeline deployment. Therefore, for the offshore area, it is necessary to carry out more careful pipeline planning and layout to ensure that the pipeline can be transported smoothly under the limitation of various uses.

4   CONCLUSIONS

Through the overlay analysis of geographic information, this paper comprehensively considers the factors such as water depth, sediment type, seabed slope, sea area ownership, ocean wave height and sea surface wind speed, and completes the production of the suitability zoning map of submarine pipeline layout, which provides a way of thinking for the routing planning of submarine pipeline layout. From the suitability zoning map, we can draw the following conclusions: the main limiting factor for pipeline layout is water depth, especially in deep water areas; the central part of the study area is mainly rock bottom, and there is a certain amount of mud base. The evaluation area suitable for mining of this type of bottom is consistent with the natural conditions of the sea area. A large area of sandy sediment in the eastern and central regions is suitable for mining. In general, the suitability of submarine pipeline layout in the study area is high, which is closely related to the terrain characteristics and sediment distribution. The sea area of Guangdong Province is flat with little fluctuation, which is consistent with the actual results. The comprehensive analysis results show that the selected suitability index is consistent with the actual results, which verifies the accuracy of the suitability evaluation of submarine pipeline layout.

References

1. Han Yunye, Ren Zhen, He Wei. He, etc. The practice of determining the weight of synergistic effect evaluation index system of large-scale scientific engineering projects based on structural entropy weight method [J]. Economist, 2022 (10) : 19-21
2. Jin Fengying, Zhang Feng, Du Zhenhong, etc. Spark-based spatial overlay analysis method for land use vector data [J]. Journal of Zhejiang University (Science Edition), 2016,43 (01): 40-44.
3. Mao Liang, Li Honghui, Jia Meilan, etc. Evaluation of clay rock preselected area of high-level radioactive repository based on ArcGIS [J]. Environmental science and management, 2019,44 (09): 180-185
4. Qu Junsheng, Liu Wenli, Cai Lianbo. Development of Submarine Pipeline Laying and Pipe Laying Vessels in China [J]. China Water Transportation (Second Half Month), 2013,13 (09): 311-313.
5. Sun Yaru, Dong Zengchuan, Zhou Yi, etc. Evaluation of water resources carrying capacity in the lower reaches of the Yangtze River based on structural entropy weight method-Taking Nanjing as an example [J]. People 's Yangtze River, 2018,49 (07): 47-51.DOI: 10.16232 / j.cnki.1001-4179.2018.07.010.
6. Tan Gang, Hao Fangping. Agricultural Flood Loss Assessment Based on GIS Overlay Analysis [J]. Science and Technology Innovation, 2020 (23): 13-15
7. Tong Yujun. Discussion on the laying method of submarine pipeline [J]. Silicon Valley, 2011 (04): 5.
8. Wang Lizhao, Jiang Zhiyuan. Research on financial risk assessment of P2P platform based on structural entropy weight method [J]. Journal of Systems Science, 2020,28 (02) : 95-99 + 128.
9. Yang Yizhou, Wu Lixin, Guo Jiateng, etc. Suitability evaluation of land space development based on parallel superposition [J]. Journal of Northeast University (Natural Science Edition), 2021,42 (11): 1585-1590.
10. Zu Fuhao, Zhao Qiuhong. Research on the evaluation method of maritime rescue aviation emergency resource layout based on structural entropy weight method and HFWGHM operator [J]. Mathematics practice and understanding, 2019,49 (19): 128-138.
11. Alrsai M. Numerical analysis and optimization of CFRP buckle arrestors in subsea pipelines[J]. Marine Structures,2024,94103574-.
12. Karabaić D, Kršulja M, Maričić S, et al. The Optimization of a Subsea Pipeline Installation Configuration Using a Genetic Algorithm[J].Journal of Marine Science and Engineering,2024,12(1).