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Research Article

Application of Theoretical Method for Comprehensive Classification of Formation Drillability Parameters in Bohai Oilfield

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Abstract: The aim of this study is to research the method to estimate the drillability parameters in Bohai oilfied. We recommend to use weighted correlation for grey relation clustering. The so-called grey relation clustering is to judge the similarity of comparative series (also known as sub-series) and reference series based on grey relational analysis. Generally, the more similar are the geometric shapes of them, the more similar are their change trends and the larger is their correlation degree. Clustering is conducted according to the maximum correlation degree identification principle.

Keywords: Drillability, formation, weighted correlation

INTRODUCTION

The mechanical properties of rocks refer to the mechanical characteristics of rocks during the process from deformation to breaking under the action of external forces, e.g. hardness, plasticity, drillability and abrasiveness etc. Those mechanical properties are single and relatively independent. Rock breaking is influenced by various rock properties jointly. It is essential to select bit based on the mechanical properties of rocks by combining those properties organically. With cluster analysis method, combine the rock grades of drillability, hardness, plasticity, shear strength into a comprehensive rock grade value, so as to describe the difference of rock drilling characteristics in a quantitative manner and provide reliable basis for bit selection. There are a lot of literatures to introduce the method to calculate the formation drillability. The researchers at home and abroad has made a lot of great achievements in mathematics foundation, rock mechanics fractal phenomena, fractal mechanism and the application of fractal research (Jaeger and Cook, 1976; Mandelbrot, 1982; Moyuru *et al*., 1992). Xue *et al*. (2002) has deduced parallel and vertical level two direction drillability formula by the p-wave velocity. In this study we use the existing grey relational method to estimate the drillability parameters. We will introduce this method in following sections.

CALCULATION METHODS

- Determine the comparative series (also known as sub-series) and the reference series:

Given that the sub-series composed of k parameters and m samples is as below:

$X_i = \{X_i(k)|k = 1, 2, \dots n\}(i = 1, 2, \dots m)$; The reference series is: $X_{oi} = \{X_{oi}(k)|k = 1, 2, \dots n\}(i = 1, 2, \dots m)$.

- Work out the correlation coefficient:

$$\xi_i(k) = \frac{\underset{i}{Min}[\underset{k}{Min}\,\Delta i(k)] + \zeta\,\underset{i}{Max}[\underset{k}{Max}\,\Delta i(k)]}{\Delta i(k) + \zeta\,\underset{i}{Max}[\underset{k}{Max}\,\Delta i(k)]} \tag{1}$$

$$\Delta i(k) = |X_{0i}(k) - X_i(k)| \tag{2}$$

where, ζ is resolution ratio within the interval [0, 1]. The smaller ζ is, the larger the resolution. Generally, ζ = 0.5.

- Work out the correlation degree:

Two methods are available for calculation of correlation degree, i.e., equal processing and non-equal processing. The non-equal processing method is more practical. Hence:

$$\gamma_i = \sum_{k=1}^{n} \xi_i(k) \cdot \alpha(k) \tag{3}$$

where,

γ_i = Grey correlation degree
$\alpha(k)$ = Corresponding weight assigned according to the importance:

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Table 1: Scale and meaning of judgment matrix

Scale	Meaning
1	Factor μi and Factor μj are equally important
3	Factor μi is more important than factor μj
5	Factor μi is important than factor μj
7	Factor μi is strongly important than factor μj
9	Factor μi is extremely important than factor μj

(2, 4, 6 and 8 refer to the median value of neighboring judgment 1~3, 3~5, 5~7 and 7~9)

$$\sum_{k=1}^{n} \alpha(k) = 1, \qquad \alpha(k) \geq 0 \tag{4}$$

When calculating the grey correlation degree, it is required to determine the weight α (k) (important influence factor to clustering results) properly. The common weight determination methods include expert estimation, frequency statistics analysis, principal component analysis, fuzzy inverse equation process and analytic hierarchy process. According to comparison and analysis of various methods, analytic hierarchy process for calculating the weight assignment of evaluation indexes can largely reduce the subjective factors. Hence, analytic hierarchy process is selected.

Analytic hierarch process was put forward by the famous operation research expert T.L. Saaty in 1970s. It divides the factors of a complex problem into relational well-organized hierarchies and makes them in order. Additionally, it directly combines the data, expert opinions and subjective judgment of analyzers in an effective way, provides quantitative demonstration for relative importance of each hierarchy and determines the relative importance weight for demonstration of all factors on each hierarchy through mathematical method. The procedures are as follows:

- Determine the objective and evaluation factors
- Build up the judgment

Let A represent the objective, μi represent the evaluation factor (i = 1, 2, ..., n), μij represent the relative importance value for μi with respect to μj (i, j = 1, 2, ..., n). See Table 1 for value of μij.

A matrix will be obtained according to the meanings of symbols above:

$$\tilde{\mu} = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1n} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{nn} \end{bmatrix} \tag{5}$$

The formula above is called A-$\tilde{\mu}$ judgment matrix.

- **Sequence of calculation importance:** Solve the eigenvector corresponding to the maximum latent root according to A-$\tilde{\mu}$ matrix. The normalized eigenvector is the importance sequence of evaluation factors, i.e., weight assignment. The calculation methods of eigenvector include power method, root method and sum root method. Sum root method is adopted in this study and its detailed procedures are as follows:

Step 1: Normalize each column of the judgment matrix

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (i, j = 1, 2, \ldots, n) \tag{6}$$

Step 2: Add up the rows of matrix after normalization:

$$\overline{W_i} = \sum_{j=1}^{n} a_{ij} \quad (i = 1, 2, \ldots, n) \tag{7}$$

Step 3: Normalize $\overline{W}$i:

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}} \quad (i = 1, 2, \ldots, n) \tag{8}$$

So, W = $[W_1\ W_2 \ldots Wn]^T$ is the solved eigenvector?

Step 4: Calculate the maximum Eigen value

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{9}$$

where, $(AW)_i$ represents the i'th element of vector AW.

- **Consistency check:** To determine whether the weight is distributed reasonably, it is required to do consistency check for the judgment matrix. The check formula is:

$$GR = \frac{GI}{RI} \tag{10}$$

$$GI = \frac{1}{n-1} \left(\lambda_{max} - n\right) \tag{11}$$

where,
GR = Random consistency check of judgment matrix
GI = Average consistency index of judgment matrix
RI = General Consistency index of judgment matrix

When GR<0.10, it is considered that the judgment matrix has satisfying consistency and the weight distribution is reasonable. Otherwise, adjust the judgment matrix for a satisfying consistency.

Table 2: Rock mechanics parameters statistical result

	Compressive strength (MPa)				Angle of internal friction (°)			
Section (m)	Max.	Min.	Average	Fnonhomogeity	Max.	Min.	Average	Nonhomogeity
0~1500 m	37.5	14.4	25.95	0.22	15.1	6.3	10.7	0.15
1500~2000m	137.2	35.4	86.3	0.19	75.3	13.6	44.45	0.27

Table 3: Rock mechanics parameters statistical result

	Hardness (MPa)			
Section (m)	Max.	Min.	Average	Nonhomogeity
01500~m	700.2	200.7	450.45	0.22
1500~2000m	1300.7	400.5	850.6	0.25

Table 4: Rock mechanics parameters statistical result

	Drillability			
Section (m)	Max.	Min.	Average	Nonhomogeity
0~1500 m	3.15	1.41	2.28	0.17
1500~2000 m	5.1	1.2	3.15	0.20
2300~3100 m	5.78	3.34	4.56	0.1
3100~3600 m	6.41	3.40	5.17	0.08
3600~4707 m	8.16	4.25	6.24	0.07

- **Build up clustering vector and clustering analysis:** For a given standard reference series Xoi (K) and a reviewing object X (K), take X (K) as the reference series and Xoi (K) as the comparative series, then:

$$\gamma_{oi} = \gamma(X, X_{oi}) \quad (12)$$

Then, X (K) must be allocated preferentially, so:

$$\underset{i}{Max}(\gamma_{oi})_{(i = 1,2,\ldots,n)} \quad (13)$$

In X_{oi}(K). That is to say, the reviewed series X (K) belongs to the category of standard reference series X_{oi} (K).

- **Formation classification:** Conduct comprehensive classification for different formations according to the clustering analysis results and classification principles.

EXAMPLE

According to the upper principle and BoHai gas formation characteristics; this study has calculated the rock mechanics parameter statistics in this zone. The results are shown in the Table 2 to 4.

CONCLUSION

The weighted correlation for grey relation clustering is to judge the similarity of comparative series (also known as sub-series) and reference series based on grey relational analysis. Generally, the more similar are the geometric shapes of them, the more similar are their change trends and the larger is their correlation degree. Clustering is conducted according to the maximum correlation degree identification principle. This study uses the weighted correlation method to analyze the comprehensive classification of formation drillability parameters in Bohaioilfied.

Through the comparision between calculation results and field data, this method is very effective.

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