# Research on Wellbore Instability Prediction Method Based on The Fuzzy Evaluation

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**Abstract.** With the increasing depth of drilling and the increasing complexity of geological conditions, the wellbore instability has become an important factor affecting the drilling construction. Accurate prediction of wellbore instability and corresponding preventive measures have significant effects on shortening drilling cycle and improving economic benefits. This paper proposes a prediction method of wellbore instability based on fuzzy comprehensive evaluation technology based on expert domain knowledge. The experimental results show that the accuracy of this method is high, however, there are still problems such as difficulties in data collection of influencing factors and poor real-time performance, which needs to be continuously improved in future research.

**Keywords:** wellbore instability, fuzzy evaluation, clustering, membership function.

## 1 Introduction

In the process of drilling, wellbore instability will often occur, which will cause problems such as jamming, obstruction of starting and descending drilling, irregular good diameter, etc., which will seriously affect the logging, cementing, and drilling cycle, which will not only have a huge impact on economic benefits but also determine the success or failure of a drilling mine; Wellbore instability has long been a problem that plagues drilling construction. In recent years, with the depletion of shallow oil reserves, the drilling depth is getting larger and larger; the geological conditions faced by drilling are becoming more and more complex; and construction is becoming more and more difficult. Wells with complex structures, such as ultra-long horizontal wells and large displacement wells, account for an increasing proportion of the total number of drilling projects, so the problem of wellbore instability during drilling has become more serious than ever, according to publicly available data, wellbore instability has reached 24% of the loss caused by downhole complications during the drilling pro-


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cess, making it the most common and complex downhole situation and accident we face, as well as the most influential problem on economic benefits. How to accurately predict wellbore instability is a technical problem that we urgently need to solve.

Changqing Drilling collects a lot of accident cases every year, and correctly analyzing and processing historical big data and finding patterns from historical data centers will help optimize drilling technical solutions and reduce accidents caused by wellbore instability. In this paper, a method for predicting wellbore instability based on fuzzy comprehensive evaluation is introduced, and the experimental results show that this method can accurately judge the occurrence of wellbore instability.

## 2 Related work

In the research of wellbore instability prediction, many domestic universities and research institutions have proposed their own methods. In 2001, Jin Yan and others from China University of Petroleum analyzed the well wall stability and used the BP algorithm to establish a pre-drilling prediction neural network model, and then used the layer speed to predict the well wall stability [1]. In 2015, Wu Chao and others from the Institute of Petroleum Engineering Technology of China Petroleum and Chemical Corporation investigated and used seismic data inversion modeling to predict the stability of the well wall by the inversion method according to the characteristics of the inversion model and the well wall stability parameters [2]. In 2019, Ma Tianshou and others of Southwest Petroleum University established a wellbore instability risk assessment method based on reliability theory, analyzed the influence of the uncertainty of various input parameters on the well wall stability, and concluded that improving the accuracy of in-situ stress can effectively improve the stability of the wellbore [3]. In 2021, Ding Liqin et al. of the China University of Geosciences established a new model for real-time prediction of well wall stability to analyze the stress and failure around the well wall by considering the elasticity and strength anisotropy of stratigraphic strata, which is of great help to accurately predict the well wall stability during the drilling process of stratigraphic strata [4].

There are also many methods of well wall prediction abroad. In 2011, Mostafavi et al. proposed a new method for evaluating the uncertainty of well wall stability, established a well wall stability uncertainty model considering input variance, and emphasized the importance of the accuracy of various parameters for well wall stability through the results.[5] In 2015,Gomar et al. used a thermoporosity-mechanical model of fully coupled conduction and convection migration to study the stress distribution around the bare borehole by the two-dimensional finite element method and used four rock strength criteria, including Mohr-Coulomb, Drucker-Prager, Modified Lade, and Mogi-Coulomb, to test the well wall stability of vertical and inclined boreholes[6]. In 2018, Lin et al. proposed the use of empirical modal decomposition (EMD) to filter the input data, thereby improving the accuracy of artificial neural network (ANN) models in predicting wellbore instability [7]. In 2019, Kamgue Lenwoue et al. believed that the elastic model and the Mohr-Coulomb criterion were not accurate enough to evaluate the well wall stability, so the Mogi-Coulomb criterion was used to analyze the well wall stability [8]. In 2020, Bahrami et al. based on previous research proposed that the improved Lade failure criterion be used as the most accurate failure criterion and found that, compared with the application of other failure criteria, the application of the improved Lade failure criterion could accurately predict the well-bore instability without the input of reservoir structure boundary knowledge or core test data [9].

## 3 Factors affecting the wellbore instability

For shale wall wells, experts have given six factors that affect their stability, namely expansiveness, recovery, density, cation exchange capacity, Zeta potential and water activity. For this purpose, expansion rate experiment, rolling recovery rate experiment, cation exchange capacity CEC test, ζ potential test, formation water activity and density tests were carried out, and a total of 19 sets of experimental data were collected, as shown in Table 1.

**Table 1.** Experimental data set

| No. | Distensibility % | Recovery % | Cation Exchange Capacity CEC mmol/100 g | Zeta potential mv | Water activity | density g/cm3 |
|---|---|---|---|---|---|---|
| 1 | 4.97 | 92.87 | 7.48 | 10.29 | 0.83 | 2.74 |
| 2 | 5.65 | 96.76 | 7.66 | 10.47 | 0.87 | 2.69 |
| 3 | 7.59 | 88.15 | 4.26 | 9.18 | 0.83 | 2.65 |
| 4 | 11.05 | 84.86 | 2.76 | 7.15 | 0.85 | 2.75 |
| 5 | 6.66 | 98.32 | 5.18 | 7.55 | 0.75 | 2.59 |
| 6 | 9.79 | 94.23 | 7.35 | 8.64 | 0.81 | 2.67 |
| 7 | 6.69 | 99.45 | 2.28 | 8.86 | 0.85 | 2.65 |
| 8 | 12.57 | 89.15 | 8.76 | 16.32 | 0.79 | 2.72 |
| 9 | 11.69 | 97.37 | 7.66 | 17.64 | 0.78 | 2.63 |
| 10 | 12.14 | 97.24 | 7.93 | 13.81 | 0.86 | 2.74 |
| 11 | 11.99 | 82.86 | 8.06 | 11.88 | 0.80 | 2.69 |
| 12 | 8.34 | 96.19 | 7.47 | 14.18 | 0.76 | 2.65 |
| 13 | 11.45 | 89.48 | 7.46 | 8.23 | 0.76 | 2.77 |
| 14 | 11.16 | 97.23 | 5.93 | 11.18 | 0.85 | 2.76 |
| 15 | 9.78 | 94.21 | 7.32 | 8.61 | 0.84 | 2.66 |
| 16 | 6.68 | 99.41 | 2.26 | 8.83 | 0.83 | 2.64 |
| 17 | 4.94 | 92.85 | 7.48 | 10.28 | 0.81 | 2.73 |
| 18 | 5.62 | 96.73 | 7.64 | 10.47 | 0.85 | 2.69 |
| 19 | 7.59 | 88.13 | 4.24 | 9.16 | 0.84 | 2.63 |

## 4 Prediction method based on fuzzy comprehensive evaluation

The Fuzzy Comprehensive Evaluation Method is a comprehensive evaluation method based on fuzzy mathematics. This method transforms qualitative evaluation into quantitative evaluation according to the membership theory of fuzzy mathematics; that is, fuzzy mathematics is used to make an overall evaluation of objects constrained by various factors [10].

Comprehensive evaluation requires the determination of three aspects: the factor set, the comment set, and the weight set. In our comprehensive evaluation method, the factor set F = {f1,f2,f3,f4,f5,f6}, where f1 is the expansiveness, f2 is the recovery, f3 is the cation exchange capacity, f4 is the zeta potential, f5 is the water activity, and f6 is the density.

The comment set E={e1,e2,e3,e4,e5}, e1 represents good, e2 represents better, e3 represents average, e4 represents slightly worse, e5 represents poor, and is divided into 5 grades.

The weight set W={w1, w2, w3, w4, w5, w6}, which is mainly based on the ex-pert's domain knowledge for each attribute in the factor set, the obtained weights wi, and Σwi=1, corresponding to the weights of (0.3, 0.3, 0.15, 0.12, 0.08, 0.05,).

After incrementally sorting each column of data, we select the 1st, 5th, 10th, 15th, and 19th data as the boundary values of the five evaluation criteria, as shown in Table 3. Among them, density is an indicator of efficiency, and a larger value indicates that the stability of the wellbore is higher. The remaining indicators (expansiveness, recovery, cation exchange capacity, zeta potential and water activity) are cost indicators, and smaller values indicate higher wellbore stability.

**Table 2.** Grading values of indicators in the fuzzy comprehensive evaluation

| Impact factor | Excellent | Good | Medium | Fair | Poor |
|---|---|---|---|---|---|
| Distensibility | 4.94 | 6.66 | 8.34 | 11.45 | 12.57 |
| Recovery | 82.86 | 89.15 | 94.23 | 97.24 | 99.45 |
| Cation exchange capacity | 2.26 | 4.26 | 7.46 | 7.66 | 8.76 |
| Zeta potential | 7.15 | 8.64 | 10.28 | 11.88 | 17.64 |
| Water activity | 0.75 | 0.79 | 0.83 | 0.85 | 0.87 |
| Density | 2.77 | 2.74 | 2.69 | 2.65 | 2.59 |

According to the number of evaluation indicators, the quality classification of wellbore stability and its membership at all levels, a fuzzy matrix was constructed.

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & & r_{nm} \end{bmatrix}$$

Where m represents the number of factors i=1, 2, 3, ..., m, in this method is 6, n represents the level of each factor j=1, 2, 3, 4, ..., n 5 in this item.

In each evaluation criterion, only the boundary value is actually calculated to have a probability value of exactly 1, and the trapezoidal distribution of the intermediate type will become a triangle. The trapezoidal distribution function of density is first decreasing and then increasing; The trapezoidal distribution function of other indicators is to increase first and then decrease. Among them, 1 small and 1 large trapezoidal membership function, 3 intermediate triangle functions, the function curve is shown in Figure 1:

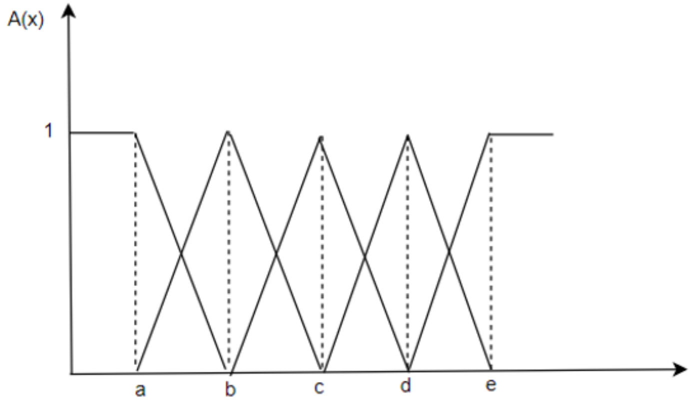


**Fig. 1.** The member function curve

The formula is shown as below:

Membership function of the small trapezoidal distribution:

$$A_{i1} = \begin{cases} 1 & x \le a \\ \dfrac{b-x}{b-a} & a < x < b \\ 0 & x \ge b \end{cases} \tag{1}$$

Intermediate triangular distribution membership function1:

$$A_{i2} = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a < x \le b \\ \dfrac{b-x}{c-b} & b < x < c \\ 0 & x \ge c \end{cases} \tag{2}$$

Intermediate triangular distribution membership function2:

$$A_{i3} = \begin{cases} 0 & x \le b \\ \dfrac{x-a}{b-a} & b < x \le c \\ \dfrac{b-x}{c-b} & c < x < d \\ 0 & x \ge d \end{cases} \tag{3}$$

Intermediate triangular distribution membership function3:

$$A_{i4} = \begin{cases} 0 & x \le c \\ \dfrac{x-a}{b-a} & c < x \le d \\ \dfrac{b-x}{c-b} & d < x < e \\ 0 & x \ge e \end{cases} \tag{4}$$

Membership function of a large trapezoidal distribution:

$$A_{i5} = \begin{cases} 0 & x \le d \\ \dfrac{x-d}{e-d} & d < x < e \\ 1 & x \ge e \end{cases} \tag{5}$$

In this way, each record becomes a matrix, such as record 1 (4.97, 92.87, 7.48, 10.29, 0.83, 2.74) converted into matrix M

$$\begin{bmatrix} 0.98 & 0.02 & 0 & 0 & 0 \\ 0 & 0.27 & 0.73 & 0 & 0 \\ 0 & 0 & 0.9 & 0.1 & 0 \\ 0 & 0 & 0.99 & 0.01 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \tag{6}$$

The resulting matrix R=W*M, W is the weight vector, and the result is (0.294, 0.137, 0.5509, 0.0181, 0). According to the principle of maximum membership, the stable state corresponding to the record is generally stable. The other 18 were evaluated using the same method, and the evaluation results were compared with the real wellbore instability of the sampled drilling, and 15 of the 19 records matched with the accuracy of 78.9%.

## 5 Conclusions

Wellbore instability prediction in drilling process has long been a difficult point in research, this paper proposes a prediction method based on fuzzy comprehensive evaluation, experimental results show that the accuracy of the method is as high as 78.9%, which is obviously better than the previous unsupervised clustering method, the main reason is that this method relies on the experience of domain experts to give the weight of each influencing factor, has a good prior knowledge, the disadvantage is that the data of influencing factors need to be tested in a laboratory environment, and it is difficult to achieve real-time prediction. Real-time prediction of wellbore instability will become our next research goal.

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