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The Application of Fuzzy Comprehensive Evaluation in Deepwater Gas Well Testing String Risk Assessment

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Abstract
Offshore Testing is a world-wide difficult problem with high danger and high risk. Many technical problems in the field of national offshore oil production are still pending. The safety of testing string is affected by multiple complex factors, and it is a complicated nonlinear problem with marked deformation and indeterminacy. The traditional risk assessment methods no longer meet the need for risk assessment of testing string. This paper adopts fuzzy comprehensive evaluation, which is based on the AHP (analytic hierarchy process) to assess the security of strings of deepwater gas well. First of all, it makes model, analyses the factors of the risk, divides the hierarchy and adopts AHP (analytic hierarchy process) to determine the weight of each factor. Secondly it seeks the experts' reviews to establish the aggregation of comments, researches the effect of each assessment factors, makes fuzzy assessment of each factor, and makes fuzzy information of many describing different aspects of the object which has different dimensions quantification. Lastly, it makes fuzzy comprehensive evaluation in order to make sure the risk assessment level of testing string and achieve quantitative analysis of the risk factors that effect testing string and assess the safety of testing string scientifically.

Key words: Testing string; Risk assessment; Fuzzy comprehensive evaluation; AHP (Analytic Hierarchy Process).

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1. INTRODUCTION

Deepwater production conditions make testing tools, well-head equipments and surface flow system stay in bad condition. It is easy to happen the failure of packer, perforating gun, well-head equipments and testing sensor and destruction of testing string, so deepwater gas well testing operations is a high-risk work process. The safety of testing string produces direct effect on the rate of testing success and the economics of oil and gas field development and construction companies. The safety evaluation to the overall performance of testing string is an important standard to detect hidden problems and technical quality in order to avoid heavy losses.

Testing string system is a complex mechanical system, which has the characteristics of diversity, multi-level, fuzziness and randomness. The assessment of safety and reliability involves a variety of factors. And the concept of some factors is vague. Many times you can only make a qualitative description. This article uses fuzzy comprehensive evaluation principle and focus on application of AHP to determine the weights of every level factors and expert appraisal. For the testing string design of one deepwater gas field in the South China Sea for example, it determines the membership of each factor and finally uses weighted average method to determine the result of comprehensive evaluation. This method solves the problem of dealing with fuzzy factors in the quantitative evaluation process, making evaluation results more scientific and rational. [1]

2. MULTI-LEVEL FUZZY COMPREHENSIVE EVALUATION MODEL [2-8]

Fuzzy comprehensive evaluation method is a analysis evaluation method which uses fuzzy mathematics to distinguish the advantage and disadvantage of things and system and makes the qualitative problem which it is difficult to quantify available to be transformed into quantitative, mainly to fuzzy reasoning of combined qualitative and quantitative, unity precision and non precision. That is under the given evaluation index, to generate comprehensive evaluation after fuzzy transformation.

2.1 Establishment of Index System Set

Index system that factors, which is a set of a variety of factors that affect the evaluation. Usually expressed with U:

$$U = \{U_1, U_2, U_3 \cdots, U_m\} \quad (1)$$

2.2 Establishment of Weight Set

To reflect the importance of each index factor, every factor should be given a corresponding weight α_i, its rationality will affect the rationality of assessment results. The set of weights is:

$$A = \{a_1, a_2, a_3, \cdots a_m\} \quad (2)$$

A is the set of factors' weights, α_i is the weight and satisfy

$$\sum_{i=1}^{m} a_i = 1(a_i \geq 0) \quad (3)$$

2.3 Establishment of Evaluation Set

Evaluation set is set up by all the evaluation results that the appraiser may make to the object. According to the specific circumstances, the evaluation criteria are divided into several levels. Usually expressed with V:

$$V = \{v_1, v_2, v_3, \cdots, v_m\} \quad (4)$$

2.4 Determine Membership to Construct Evaluation Matrix[9]

There are many methods to determination the membership function, different situations using different methods. Usually use the fuzzy statistical method. The experts or related personnel rate the evaluation factors, calculate the results of rate and normalized, so as to determine the fuzzy evaluation matrix. However it can be used **Delphi-method** that depended on people's experience and judgment, which is difficult to use fuzzy statistical method to determine the membership function. Fuzzy evaluation matrix is:

$$R = \{R_1, R_2, R_3, \cdots R_n\} \quad (5)$$

$R_i = \{r_{i1}, r_{i2}, r_{i3}, \cdots r_n\}$ is the fuzzy evaluation vector of the i element.

2.5 Fuzzy Comprehensive Evaluation

Make fuzzy operation between weight vector of evaluation factors and fuzzy evaluation matrix so as to determine the result of fuzzy evaluation. [10]

$$B = A \circ R = \{b_1, b_2, b_3, \cdots b_m\} \quad (6)$$

3. MULTI-LEVEL FUZZY COMPREHENSIVE EVALUATION OF TESTING STRING

3.1 Establish Index System Set of Testing String

Analysis the composition of deep gas well testing string and combined expertise so as to creat Figure 1 which shows the two-level factors' set.

3.2 Determine the Weights of Index Factors With AHP

First of all, according to the different levels to construct evaluation matrix , given the relative importance of indicators by twos, with the natural number 1, 2, ---, 9, and the reciprocal of these.1 means that two indicators are equally important; 3 means that the former than the latter slightly important; 5 means that the former than the latter obviously important; 7 means that the former than the latter strongly important; 9 means the former than the latter extremely important; and 2, 4, 6, 8 between adjacent evaluation. Then, calculate the weights of each group, and make the consistency test.

Normalized the columns elements of evaluation matrix, sum each element of each row in the normalized evaluation matrix, and then normalized the sum. The vector is the weight vector which is needed. Calculate the largest eigenvalue of the matrix $\lambda_{\max}$ and make the consistency test.

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

$CR = \frac{CI}{RI}$ to 1-9 order evaluation matrix, the value of the average random consistency index shows in Table1. When the rate of random consistency CR≤0.10, means the results of level sort has satisfied consistency. Otherwise, need to adjust the values of evaluation matrix factors. As space is limited, we only list two examples. Calculated data shown in Table 2 to 4.

Table1
The value of testing string's safety assessment

1	2	3	4	5	6	7	8	9
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3.3 Establish the Evaluation Set of Testing String's Safety Assessment

By analyzing the failure of previous test string, according to the relevant design standards of test string, combined with the experience of experts.

Establish the following five levels of evaluation set. V={better, good, medium, worse, worst}

3.4 Determine the Membership of Testing String Evaluation Factors to Construct Evaluation Matrix

Select five experts to evaluate the evaluation factors, as an example, testing string design of one deepwater gas field in the South China Sea. According to the detailed data of the equipment that provided in the design and expertise, following the established safety assessment model, calculate the evaluation results of each single factor. According to fuzzy statistics, it models the determination of random events' probability to determine the degree of membership. In the experts' n times evaluation, index u_i belongs to evaluation v_i m times. So the membership is $\frac{m}{n}$ .The fuzzy evaluation matrix as follows:

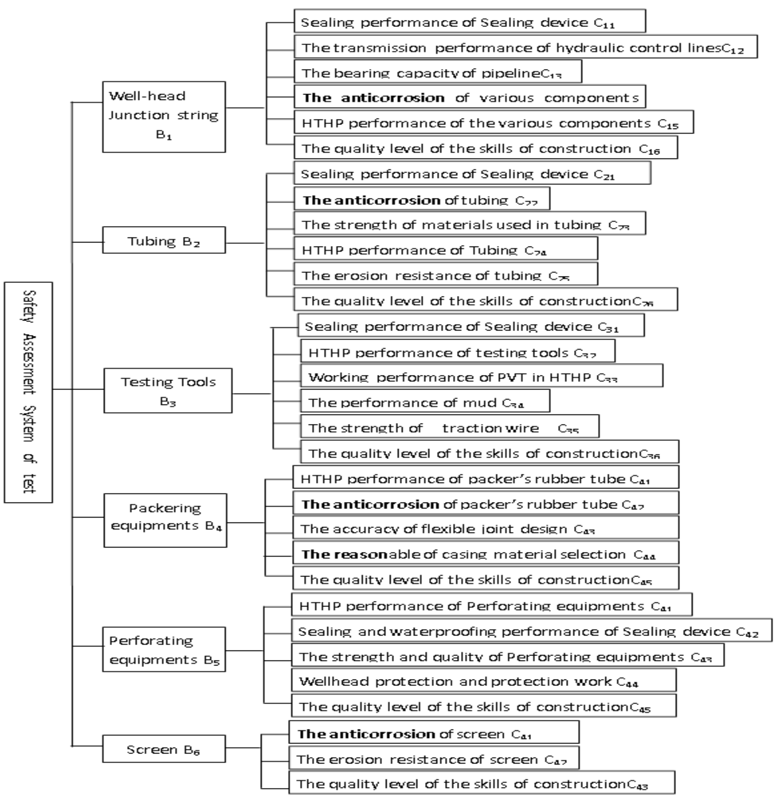

Figure 1
Safety assessment system structure chart

$$R_{B1}=\begin{bmatrix}0.2&0.6&0.2&0&0\\0&0.6&0.2&0.2&0\\0&0.8&0.2&0&0\\0.2&0.2&0.4&0.2&0\\0&0.6&0.4&0&0\\0&0.4&0.4&0.2&0\end{bmatrix}\quad R_{B2}=\begin{bmatrix}0.2&0.8&0&0&0\\0&0.6&0.4&0&0\\0&0.8&0.2&0&0\\0.2&0.2&0.4&0.2&0\\0&0.2&0.6&0.2&0\\0&0.4&0.4&0.2&0\end{bmatrix}\quad R_{B3}=\begin{bmatrix}0&0.8&0.2&0&0\\0&0.4&0.4&0.2&0\\0&0.8&0.2&0&0\\0.2&0.6&0.2&0&0\\0&0.6&0.4&0&0\\0&0.4&0.4&0.2&0\end{bmatrix}\quad R_{B4}=\begin{bmatrix}0.2&0.6&0.2&0&0\\0.4&0.4&0.2&0&0\\0.2&0.6&0.2&0&0\\0.4&0.4&0.2&0&0\\0.2&0.4&0.4&0&0\end{bmatrix}$$

Table 2
The values of testing string's safety assessment

Evaluating index	Well-head Junction string	Tubing	Testing tools	Packers equipments	Perforating equipments	Screen	Weight
Well-head Junction string	1	2	1	3	1/2	5	0.206
Tubing	1/2	1	1/2	2	1/3	3	0.118
Testing Tools	1	2	1	3	1/3	5	0.195
Packers equipments	1/3	1/2	1/3	1	1/4	2	0.073
Perforating equipments	2	3	3	4	1	6	0.365
screen	1/5	1/3	1/5	1/2	1/6	1	0.043

Consistency test: λ_{max} =6.0973, CI=0.0195, CR=0.0157<0.10, satisfy the requirements.

Table 3
The value of screen's safety assessment

Evaluating index	Anticorrosion of screen	Erosion resistance of screen	Quality level of the skills of construction	Weight
Anticorrosion of screen	1	2	3	0.538
Erosion resistance of screen	1/2	1	2	0.298
Quality level of the skills of construction	1/3	1/2	1	0.164

Consistency test: λ_{max} =3.0092, CI=0.0046, CR=0.0079<0.10, satisfy the requirements.

Table 4
The values of all the factor's weights of testing string's safety assessment

Evaluating syetem	Evaluating factors of first level	Weight	Evaluating factors of second level	Weight
Safety Assessment System of test string A	B1	0.206	C11	0.188
			C12	0.153
			C13	0.092
			C14	0.174
			C15	0.336
			C16	0.057
	B2	0.118	C21	0.231
			C22	0.104
			C23	0.384
			C24	0.158
			C25	0.074
			C26	0.049
	B3	0.195	C31	0.249
			C32	0.379
			C33	0.161
			C34	0.102
			C35	0.066
			C36	0.043
	B4	0.073	C41	0.306
			C42	0.367
			C43	0.164
			C44	0.100
			C45	0.063
	B5	0.365	C51	0.232
			C52	0.199
			C53	0.416
			C54	0.094
			C55	0.059
	B6	0.043	C61	0.538
			C62	0.298
			C63	0.164

$R_{B4}=\begin{bmatrix}0.2&0.6&0.2&0&0\\0.2&0.8&0&0&0\\0.2&0.6&0.2&0&0\\0&0.6&0.4&0&0\\0&0.4&0.4&0.2&0\end{bmatrix}$	$R_{B4}=\begin{bmatrix}0.2&0.4&0.4&0&0\\0.4&0.4&0.2&0&0\\0&0.4&0.4&0.2&0\end{bmatrix}$

Use the improved evaluation model, the evaluation results of single factor in first layer are as follows:

$$B_1=A_1\circ R_{B1}=(0.0724\ 0.5374\ 0.3134\ 0.0768\ 0)$$
$$B_2=A_2\circ R_{B2}=(0.0778\ 0.6204\ 0.2456\ 0.0562\ 0)$$
$$B_3=A_3\circ R_{B3}=(0.0204\ 0.5976\ 0.2976\ 0.0844\ 0)$$
$$B_4=A_4\circ R_{B4}=(0.2934\ 0.4940\ 0.2126\ 0\ 0)$$
$$B_5=A_5\circ R_{B5}=(0.1694\ 0.6280\ 0.1908\ 0.0118\ 0)$$
$$B_6=A_6\circ R_{B6}=(0.2268\ 0.4000\ 0.3404\ 0.0328\ 0)$$

So: $$R_B=\begin{bmatrix}0.0724&0.5374&0.3134&0.0768&0\\0.0778&0.6204&0.2456&0.0562&0\\0.0204&0.5976&0.2976&0.0844&0\\0.2934&0.4940&0.2126&0&0\\0.1694&0.6280&0.1908&0.0118&0\\0.2268&0.4000&0.3404&0.0328&0\end{bmatrix}$$

The evaluation results of second layer:

$$B=A\circ R_B=(0.1211\ 0.5829\ 0.2514\ 0.0446\ 0)$$

3.5 The Results of Testing String Risk Assessment

According to the principle of maximum degree, the evaluation result of well testing string design is counted as the Level 2, that is good. Therefore, the test program can be judged relatively safe under the testing design, there is little possibility that Occur testing fails and the accident risk. Meanwhile the results show that, the testing program in the skills of construction workers and screen quality level is relatively low assessment results, is the weak link in security, and shall take appropriate measures for improving and strengthening the skills of the quality level of training.

4. CONCLUSION

In this paper, fuzzy comprehensive evaluation method is introduced to the field of deep gas wells testing; the testing string was divided into Well-head Junction string joint top string, tubing, and other four nodes. Based on theory of fuzzy mathematics, it quantifies some evaluation factors for example description border is unclear and the equipment is not easily quantified. This paper establishes a multi-level evaluation model of testing string and applies AHP to determine weights and fuzzy comprehensive evaluation model to make assessment results more reasonable.

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