Journal of Engg. Research **Vol. 5 No. (3) September 2017 pp.** *230-243*

طريقة تحسين هيكل جسم البئر بناء على آلية التنسيق لمخاطر الحفر والتكلفة

ياه-نان شنغ*، تشي-تشوان قوان*، كاي واي و تينغ-فنغ تشاو*****
* كلية هندسة البترول، جامعة الصين للبترول (شرق الصين)، تشينغداو 266580، الصين
** كلية هندسة البترول، جامعة اليانغتسى، ووهان 434023، الصين
*** نيك شينجيانغ حقل النفط، كاراماي 834000، الصين
* مراسلة المؤلف: يا نان شنغ. البريد الإلكتروني: *shengyanan_upc@163.com*

الخــلاصــة

مع تطور حفر النفط إلى البحر والطبقة الأرضية المعقدة بالبئر العميقة، تصبح مشكلة المخاطر في عملية حفر البئر بارزة مما يؤدي إلى الترقية المستمرة لتكلفة حفر البئر. إن تحكم تكلفة حفر البئر نقطة ساخنة لبحث سلامة حفر البئر. تجهز هذه الرسالة نوعا من أسلوب تحسن هيكل جسم البئر ويطبق هذه الطريقة في توقيع مخاطر هندسة حفر البئر بخطط مختلفة هياكل جسم البئر، يقرر حسب مدى المخاطر لتقسيم المخاطر الهندسية إلى المنطقة الخطرة والمنطقة الانتقالية والمنطقة الأمنية؛ يجب اتخاذ الإجراءات في تجنب المخاطر الهندسية في المنطقة الخطرة، لا حاجة إلى اتخاذ الإجراءات في تجنب المخاطر الهندسية في المنطقة الأمنية إلا بالحفر الحذر في عملية حفر البئر؛ بالنسبة إلى المخاطر الهندسية في المنطقة الانتقالية، تجهز هذه الرسالة نموذج حساب لتكلفة معالجة المخاطر وتكلفة تجنب المخاطر، ينسق ويقيم المخاطر والتكلفة عبر مقارنة تكلفة معالجة المخاطر وتجنب المخاطر، أخيرا يتوصل إلى خطة تحسن هيكل جسم البئر على أساس المخاطر الهندسية و تنسيق التكلفة.

Casing Program Optimization Method Based on Coordination Mechanism of Drilling Risk and Cost

Ya-Nan Sheng *, Zhi-Chuan Guan*, Kai Wei** and Ting-Feng Zhao***

**School of Petroleum Engineering, China University of Petroleum (East China), Qingdao 266580, China;*

***School of Petroleum Engineering, Yangtze University, Wuhan 434023, China;*

****CNPC Xinjiang Oilfield Company, Karamay 834000, China;*

** Corresponding Author: Ya-Nan Sheng. Email:shengyanan_upc@163.com;*

ABSTRACT

Along with the development of drilling to offshore or deep and complex formation, the drilling risk is becoming more and more serious, which leads to continuous increase of drilling cost. Controlling drilling cost and ensuring drilling safety become more and more attractive. So a method was proposed to solve this problem. Firstly, the drilling risk was evaluated by the method of risk degree judgment, which was divided into the dangerous zone, transition zone and safe zone. Measure must be taken to avoid risk in the dangerous zone. The drilling process should be cautious in the safe zone without the need to avoid risk. Risk in transition zone was the focus in this paper. The risk treatment and risk aversion cost model were established to calculate the risk treatment and aversion cost. Then the coordination mechanism of risk and cost was proposed to take both safety and cost into consideration. Finally, the optimized casing program based on the coordination mechanism was presented. The case study shows that the drilling risk can efficiently be reduced based on the optimized casing program. At the same time, the cost can be reduced to the greatest extent.

INTRODUCTION

Oil and gas drilling engineering has the characteristics of high investment and high risk as well, especially when drilling in the deep and complex formation or offshore oil fields (Bratton et al., 2001; Skogdalen *et al*., 2012; Abimbola *et al*., 2016; Brandsæter, 2002). Due to the uncertainty of the drilling geological parameters, the prediction result of formation pressure is not accurate (Irrgang *et al*., 2001; Udegbunam, 2015; Lerche, 2012). It will lead to an unreasonable drilling design, which will increase the drilling engineering risk or even cause serious a drilling accident. Therefore, how to accurately predict and reasonably avoid the drilling risk is one of the most important means to achieve safe and efficient drilling. And it has also become a hot issue in domestic and foreign scholars› attention and research. In existent researching files, scholars have done a long-term research on the risk prediction and established some classic methods, which include analytic hierarchy process, fault tree analysis method, formation pressure with credibility, artificial neural network method, and so forth (Sadiq *et al*., 2003; Hong-Bo *et al*., 2008; Yuan *et al*., 2010; Khakzad *et al*., 2013; Guan *et al*., 2013). These methods can basically achieve the qualitative, semi-quantitative, or quantitative evaluation of the drilling risk. Of the available studies, the risk probability can be gotten. However, how much degree of risk should be avoided and what is the additional cost of avoiding risk are lacking from the study system. We want to try to make up for the lack of research. In this paper, we coordinated the drilling cost and risk as the dual objectives and established the optimization method of casing program design. Based on the method, the drilling risk such as kick, lost, collapse, or sticking can be efficiently reduced. At the same time, the drilling cost can be reduced to the greatest extent. According to the findings of the case study, the method established in this paper has good economic and social benefits.

DRILLING RISK DEGREE JUDGMENT

We used the fuzzy mathematical theory to construct a membership function that could judge the drilling risk degree (Guan *et al*., 2015). The method is mainly divided into two steps:

1- Establishment of risk probability: on the basis of probability density statistic model and Monte Carlo simulation, the formation pressure with credibility was obtained. Based on that, we defined four types of drilling risk by analyzing the risk mechanism. They are kick, lost, collapse, and sticking. Then the risk profile of the whole well was gotten by using the drilling risk quantitative evaluation method. The risk probability profile is shown in Figure 1.

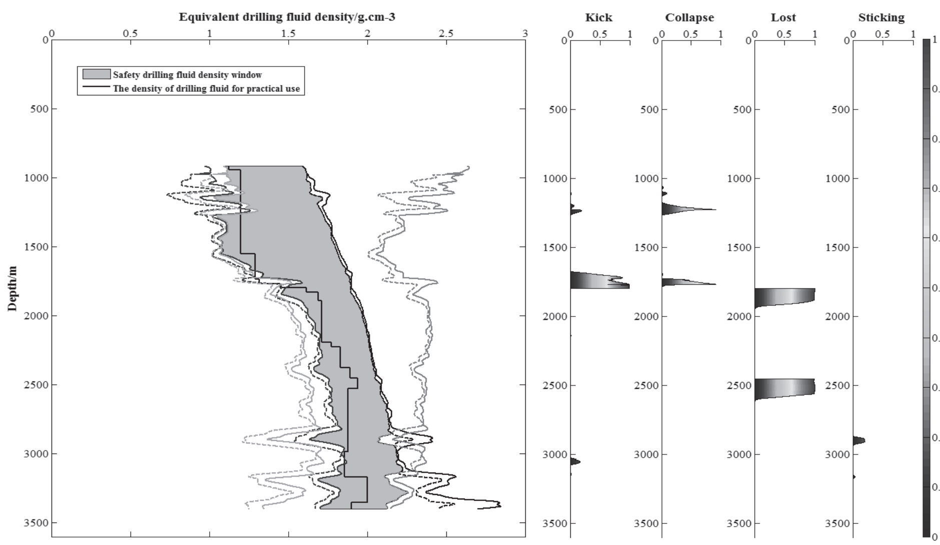

Figure 1. Schematic diagram of drilling risk prediction results.

2- Judgment of risk degree: firstly, we built the fuzzy subset samples and determined the overall distribution parameters of fuzzy subsets. Then, we established the membership function, and finally, the membership functions of the safe and dangerous zones were gotten. Based on that, we calculated the threshold of the safe zone and threshold of the dangerous zone. The risk probability profile was divided into a safe zone, dangerous zone, and transition zone. The schematic diagram of the degree of risk judgment is shown in Figure 2.

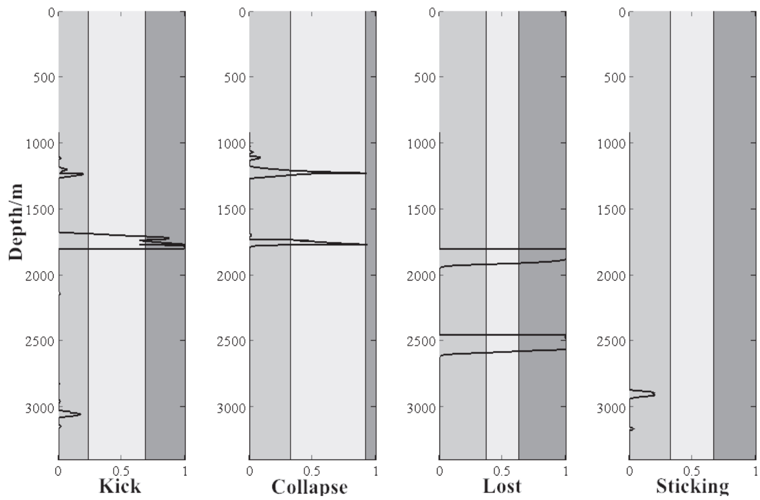

Figure 2. Schematic diagram of risk level identification.

For the risk in the safe zone (green), the actual risk probability is smaller. There is no need to take measures to avoid the risk, and we just need to drill carefully in the drilling process. For the risk in the dangerous zone (red), the actual risk probability is greater. Measures must be taken to avoid the risk. For the risk in the transition zone (yellow), both drilling risk and cost should be considered. Based on the coordination between risk and cost, we can determine whether to take measures or not. This is the focus in the study of this article.

RISK TREATMENT AND AVERSION COST CALCULATION MODEL

Taking into account the various factors that affect the cost of risk treatment, the risk treatment costs are divided into the consumable materials cost and the operating cycle cost associated with the increased drilling cycle (Guang *et al*., 2009; Wang *et al*., 2010; Leslie 2007). The cost structure is shown in Table 1.

Table 1. Cost structure of risk treatment.

Risk type	Consumable cost C_m	Operating cycle cost C_t
Kick	Cost of using drilling fluid and killing fluid	Depreciation drilling rig maintenance cost, solids control equipment expenses and fuel expenses during operating, etc.
Lost	Cost of using drilling fluid and seepage control material	Ditto
Collapse	Cost of using drilling fluid and anti-caving agent	Ditto
Sticking	Cost of using pipe free agent	Ditto

Calculation formulas of risk treatment cost are defined as follows:

$$C_K = R_K^o (C_{mk} + C_{tk}) \tag{1}$$

$$C_C = R_C^o (C_{mc} + C_{tc}) \tag{2}$$

$$C_F = R_F^o (C_{mf} + C_{tf}) \tag{3}$$

$$C_S = R_S^o (C_{ms} + C_{ts}) \tag{4}$$

where R_K^o is the probability of kick; R_C^o is the probability of collapse; R_F^o is the probability of lost; R_S^o is the probability of sticking; C_{mk} is the cost of drilling fluid and well killing fluid to deal with kick; C_{mf} is the cost of drilling fluid and plugging agent to deal with lost; C_{mc} is the cost of clay stabilizer to deal with collapse; C_{ms} is the cost of spotting agent to deal with sticking; C_{tk} is the cost of kick treatment cycle; C_{tc} is the cost of collapse treatment cycle; C_{tf} is the cost of lost circulation treatment cycle; C_{ts} is the cost of sticking treatment cycle.

In the formula, the risk probability is based on the probability value of risk degree judgment. All kinds of risk probability can be obtained by calculation with the following formula:

$$R_i^o = \begin{cases} 0 & R_{S_i} > R_i \\ \dfrac{R_i - R_{S_i}}{R_{D_i} - R_{S_i}} & R_{S_i} < R_i \le R_{D_i}, i = K, C, F, S \\ 1 & R_{D_i} < R_i \end{cases} \tag{5}$$

where R_i^o is the probability value based on the risk degree judgment; $i = K, C, F, S$, which stand for kick, collapse, lost, and sticking; R_{S_i} is the threshold of the safe zone; R_{D_i} is the threshold of the dangerous zone.

The risk aversion cost is the additional drilling cost produced by the changed casing program to avoid the risk. According to the forming factors of the additional cost, the additional cost is divided into the cost associated with the changed casing program and the cost associated with the changed drilling cycle (Sharer *et al*., 1983; Yi, 2002). The cost structure of each component is shown in Table 2.

Table 2. Cost structure of risk aversion.

Additional cost classification	Structure of cost
Cost associated with casing program parameter	Cost of pipe and cement slurry produced by the change of casing program, and the additional cost of drilling fluid produced by the change of drilling fluid related parameter
Cost associated with the drilling cycle	The operating cycle cost generated by the casing program changes

The calculated formula of risk aversion cost is defined as follows:

$$C_A = C_m + C_c + C_t \tag{6}$$

where C_A is the total cost of risk aversion; C_m is the additional cost of drilling fluid; C_c is the cost of pipe and cement slurry generated by the changed casing program; C_t is the operating cycle cost generated by the changed casing program.

The calculation of pipe and cement slurry cost is simple. The calculated formula is defined as follows:

$$C_c=\left[\sum_{i=1}^{N}\left(L_iC_{c0_i}\right)-\sum_{j=1}^{M}\left(L_j^{'}C_{c0_j}\right)\right]+\left[\sum_{i=1}^{N}\left(V_iC_{s0_i}\right)-\sum_{j=1}^{M}\left(V_j^{'}C_{s0_j}\right)\right] \tag{7}$$

where C_c is the cost of pipe and cement slurry produced by the change of the casing program; N is the new number of changed casing program; M is the original number of the designed casing program; L_i is the length of the ith size of changed casing string, m ; $L_j^{'}$ is the length of the jth size of casing string of the original plan, m ; C_{c0} is the average price per meter of casing string; V_i is the cement slurry content of the ith section of changed casing program m^3 ; $V_j^{'}$ is the cement slurry content of the *j*th section of the original plan, m^3 ; C_{s0} is the average price per cubic meter of cement slurry.

In contrast, the influence factors of the operating cycle cost and drilling fluid surcharge are relatively vague. Through field investigation and analysis, it is found that the casing running operation and drilling operation are the main activities resulting in the change of the operating cycle. Obviously, due to the change of the casing program, the time of running casing must be changed. And this time can be calculated according to the casing running speed. The calculation formula is defined as follows:

$$C_{t1}=\frac{C_d}{86400}\left[\sum_{i=1}^{N}\left(\frac{L_i}{Vc_i}\right)-\sum_{j=1}^{M}\left(\frac{L_j^{'}}{Vc_j}\right)\right] \tag{8}$$

where C_{t1} is the operating cycle cost generated by the changed time of running casing; C_d is the drilling daily cost; Vc is the speed of running casing, m/s .

$$C_{t2}=\frac{C_d}{24}\left[\sum_{i=1}^{N}\left(\frac{h_i}{Vd_i}\right)-\sum_{j=1}^{M}\left(\frac{h_j^{'}}{Vd_j}\right)\right] \tag{9}$$

where C_{t2} is the operating cycle cost generated by the changed drilling time; C_d is the drilling daily cost; h_i is the designed depth of the ith section of the changed casing program m ; $h_j^{'}$ is the designed depth of the *j*th section of the original plan m ; Vd is the average mechanical drilling speed m/h ; According to C_{t1} and C_{t2} calculated above, we can obtain the operating cycle costs generated by the change of the casing program, as shown in the following:

$$C_t=C_{t1}+C_{t2} \tag{10}$$

The calculation of additional cost of drilling fluid should consider different drilling fluid performances in different formations, and the cost will be different. Due to the changed casing program, the length of the barefoot interval also changed. In this paper, the drilling fluid in different formations was calculated by making statistical analysis based on the data of the drilled wells. Then, the additional cost of the drilling fluid of the new design can be calculated. The calculation formula is defined as follows:

$$C_m=\sum_{i=1}^{N}\left(C_{m0_i}\right)-\sum_{j=1}^{M}\left(C_{m0_j}\right) \tag{11}$$

where C_m is the additional cost of the drilling fluid.

CASING PROGRAM OPTIMIZATION BASED ON RISK AND COST COORDINATION

The steps of the casing program optimization are described below. Firstly, we should collect the data of well logging, well history, mud logging, and so on. Then, based on the uncertainty analysis method, the formation pressure with credibility was established. Next, according to the pressure constraint criterion, we established the safe window of drilling fluid density with credibility. Based on that, through the risk mechanism analysis and the reliability theory, the quantitative analysis method for the drilling risk was established. Then, the risk profile of the whole well section was gotten by the quantitative risk assessment method. The risk probability profile can be divided into a safe zone, dangerous zone, and transition zone by using fuzzy mathematics and membership function. For the risk in the safe zone, there is no need to take a measure to avoid the risk. For the risk in the dangerous zone, measures must be taken to avoid the risk. For the risk in the transition zone, both drilling risk and cost should be considered. Through the coordination between risk and cost, we can determine whether to take measures or not. Finally, the optimization of the casing program was gotten based on the coordination mechanism of risk and cost. The flow chart of the method is shown in Figure 3.

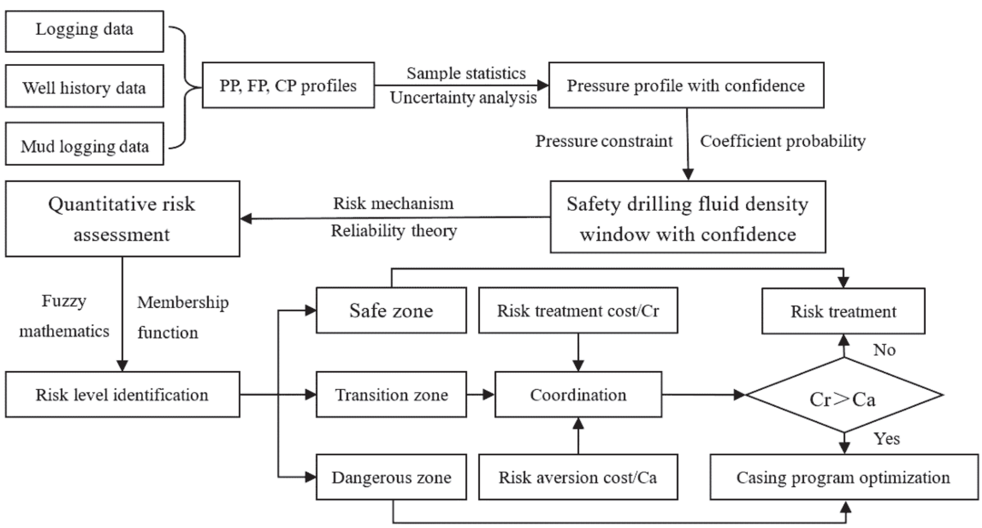

Figure 3. The schematic diagram of the casing program optimization.

RESULTS AND DISCUSSION

There were 5 drilled wells in one block of a basin in west China, among which N1, N2, N3, and N4 were selected as sample wells and N5 was selected as the target well. The risk probability profiles of the sample wells were built. Meanwhile, we counted and analyzed the well history data. Based on the method of risk degree judgment, we calculated the threshold of the safe zone R_{Si} and dangerous zone R_{Di} of all kinds of risks, which are shown in Table 3.

Table 3. Critical value of risk probability.

Risk type	Threshold of safe zone R_{Si}	Threshold of dangerous zone R_{Di}
Kick	0.2502	0.7523
Lost	0.2271	0.7535
Collapse	0.2056	0.7214
Sticking	0.2339	0.6918

The risk probability profiles and the judgment of risk degree of the target well (N5) were built. And the results are as shown in Figures 4 and 5.

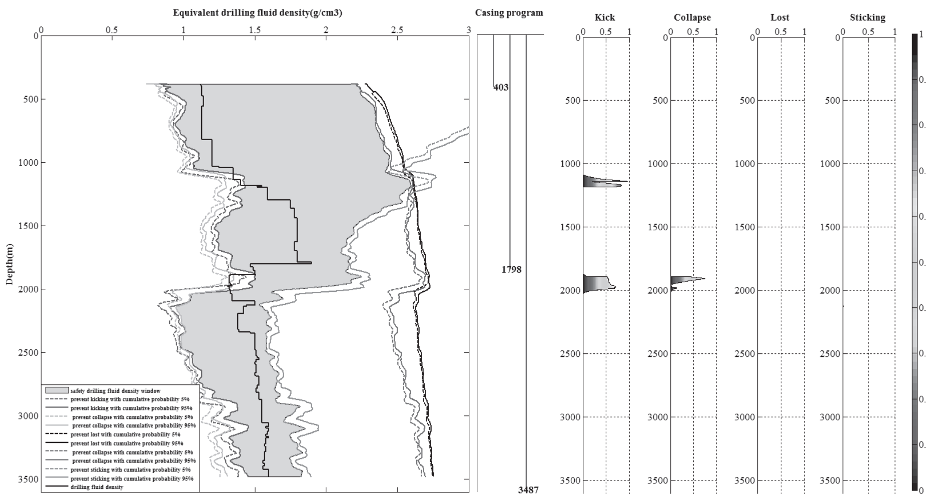

Figure 4. The basic data and risk assessment of the target well N5.

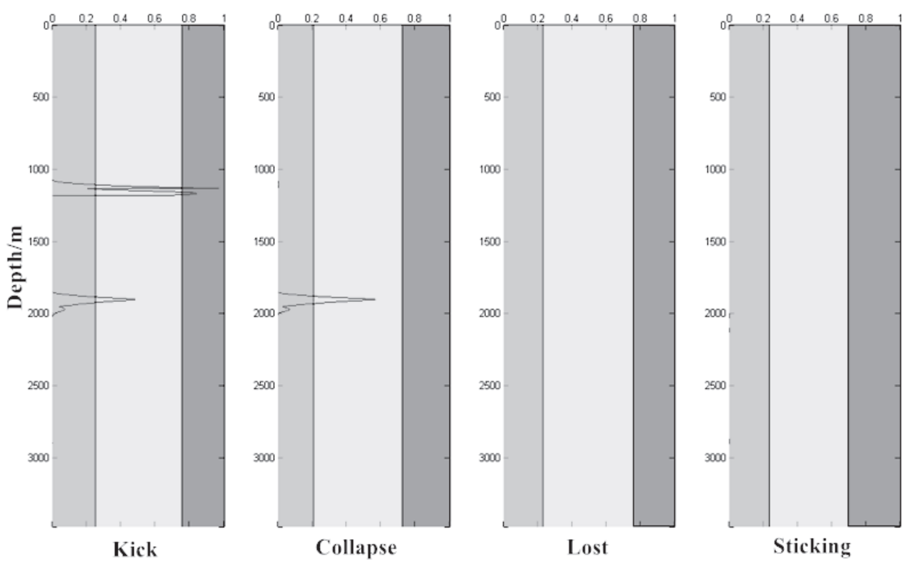

Figure 5. The risk degree judgment of the target well N5.

As shown in Figures 4 and 5, the risks of the target well were mainly kick and collapse. And the sections of kick were located in the 1100m~1200m and 1800m~2000m. The section of borehole collapse was located in the 1800m~2000m. According to the distribution of risk position, they were divided into two parts to be analyzed: the first part was 1100m~1200m interval and the second part was 1800m~2000m interval.

(1) 1100 m~1200m interval

The kick risk probability between 1100m~1200m was 0.9, which was larger than the threshold of kick (as shown in Table 3). The risk was in the dangerous zone, so measures must be adopted to avoid the risk. Analyzing the risk mechanism (Austin, 1983), the main reason for the occurrence of risk was that mud density was lower than the formation pore pressure. Therefore, we prevent the kick by increasing the mud density to 1.5 g/cm^3 with no need to adjust the casing program. The risk assessment result of the changed plan is shown in Figure 6. And the kick between 1100m~1200m was better prevented.

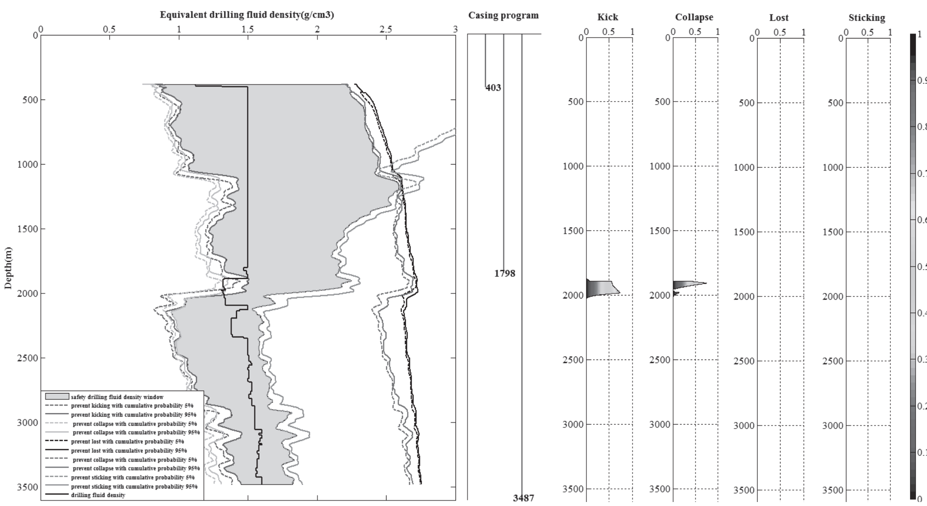

Figure 6. Risk assessment of the target well N5.

(Drilling fluid density of the second section is 1.5 g/cm^3.)

(2) 1800m~2000m interval

There were both collapse and kick between 1800m and 2000m. The maximum probability of kick was 0.6, and the maximum probability of collapse was 0.75. Combined with Table 3, we determined that these two risks were both in the transition zone. So the optimized casing program should be obtained by comparing the risk treatment and aversion cost.

1- Risk treatment cost

The mud density should be increased from 1.52 g/cm^3 to 1.6 g/cm^3 to deal with kick. Through statistical analysis of the block data, the average kick operation time of this interval was 0.85 days. According to Formula (1), the kick treatment cost (C_K) was 36289 yuan.

In order to deal with the risk of collapse, we need to add the collapse prevention agent. The potassium chloride was chosen as the collapse prevention agent, with the 5% amount of additives. And the price is 2000 yuan/t. Through statistical analysis of the block well history reports, the average collapse operation time of this interval was 0.52 days. According to Formula (2), the cost of collapse treatment (Cc) was 43316 yuan. The total cost of risk treatment (Cr) was 79605 yuan.

2- Risk aversion cost

By analyzing the risk mechanism, the main reason for the two risks' occurrence in this interval was low mud density. So the measure to avoid these two risks was proximately the same. The mud density of the third section was increased to 1.6 g/cm^3 to avoid these two risks. And the adjusted risk assessment result is shown in Figure 7.

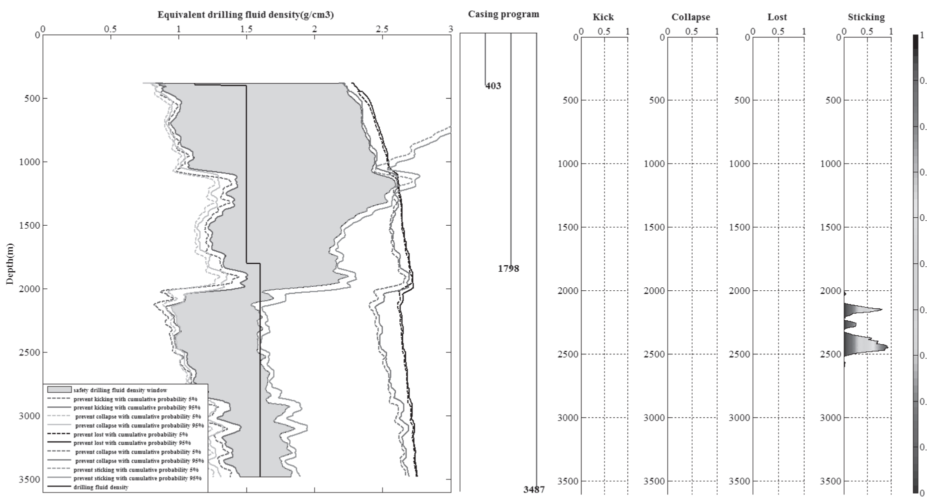

Figure 7. Risk assessment of the target well N5.
(Drilling fluid density of the third section is 1.6 g/cm^3.)

As shown in Figure 7, kick and collapse were avoided between 1800m~2000m. However, the risk of sticking was shown up between 2100m~2500m. This interval was longer, and the risk probability was larger. Therefore, it was difficult to achieve the effect of drilling risk aversion by simply adjusting mud density. It was because that the safety window of mud density at 2000m was narrow. Mud density adjustment range was limited and not easy to control. Due to the problem, it was only accessed to avoid the risk by adjusting the casing program. The intermediate casing depth of the second section was increased from 1798m to 2000m, and the mud density of the second section was increased to 1.6g/cm^3, in order to solidify the high pressure interval between 1800m and 2000m. Mud density of the third section was decreased to 1.4g/cm^3, in order to avoid sticking in the third section. The adjusted plan of the casing program was evaluated, and the result is shown in Figure 8. The drilling risks were efficiently reduced.

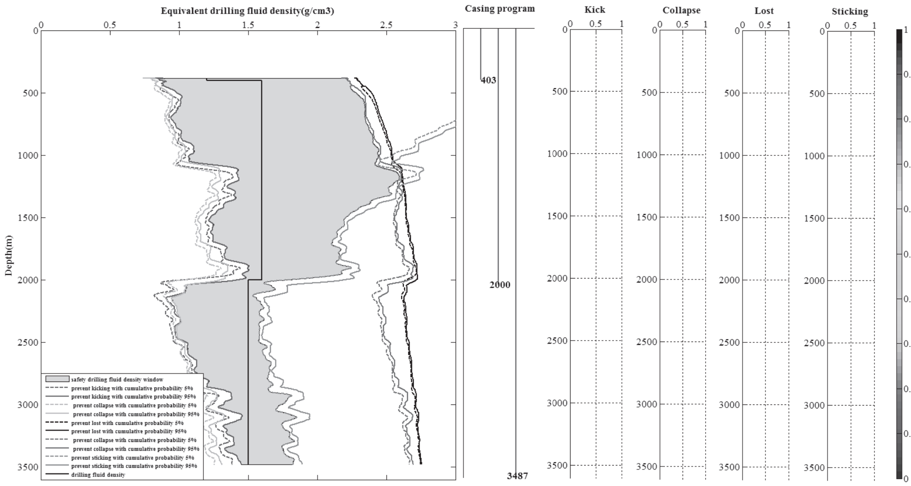

Figure 8. The risk assessment of the recommended casing program of the target well N5.

Through the investigation and research, the price of each casing tube with diameter size φ244.5mm is 2500 yuan. Its running speed is 8 tubes per hour. The drilling operation time only changed between 1800m~2000m. By searching the adjacent well history report, we found that the bit penetration rate with diameter size φ311.15mm is 3.79 m/h and the bit penetration rate with diameter size φ215.9mm is 3.10 m/h. Cement price is 1360 yuan/t, with a daily drilling pay of 76000 yuan. The original casing program is shown in Table 4.

Table 4. Original casing program of the target well N5.

Casing layer	Size /mm	Depth /m	Mud density /(g/cm^3)	Height of cement /m
The surface casing	ϕ339.7	403	1.12-1.20	Ground surface
The intermediate casing	ϕ244.5	1798	1.12-1.80	Ground surface
The production casing	ϕ139.7	3487	1.29-1.6	1700

According to the established model of the risk aversion cost, the cost associated with the changed casing program was mainly formed by the increased tube and mud expenses C_c . The cost associated with time was mainly produced by the operating cycle cost C_t. The additional cost for mud C_m was caused by the changed mud density. According to Formula (6) ~Formula (10), we calculated the risk aversion cost: $C_a=C_c+C_t+C_m=40273$ yuan.

After comparing the two costs, we found that the risk aversion cost was less than the risk treatment cost. So measures should be taken to avoid the risk. Finally, the optimization of the casing program was gotten. The optimized result is shown in Table 5.

Table 5. Optimized casing program of the target well N5.

Casing layer	Size /mm	Depth /m	Mud density /(g/cm3)	Height of cement /m
The surface casing	ϕ339.7	403	1.2	Ground surface
The intermediate casing	ϕ244.5	2000	1.6	Ground surface
The production casing	ϕ139.7	3487	1.4	1700

CONCLUSIONS

(1) The risk of drilling engineering is divided into a safe zone, transition zone, and dangerous zone, based on the risk degree judgment. For the risk in the safe zone, there is no need to take measures to avoid the risk. For the risk in the dangerous zone, measures must be taken to avoid the risk. For the risk in the transition zone, both risk and cost should be considered.

(2) This paper established the calculation model of the risk treatment and aversion cost. For the risk in the transition zone, risk aversion risk and treatment costs were calculated. Then, we comprehensively analyzed and evaluated them. Finally, the optimization of the casing program can be gotten based on a coordination mechanism of the risk and cost. Based on the optimized casing program, the drilling risk such as kick, lost, collapse, or sticking can be efficiently reduced in the drilling design phase. At the same time, the drilling cost can be reduced to the greatest extent. An example showed that the method established in this paper has good economic and social benefits.

(3) With the continuous development of the block and the increase in the drilling risk data, the membership function of the risk degree judgment will be changed. So the regional drilling risk statistics database should be established. It can achieve the real-time update of the membership function and make the classification of the risk degree judgment more practical.

ACKNOWLEDGMENT

The authors would like to acknowledge the academic and technical support of China University of Petroleum (East China). This paper is supported by the National Natural Science Foundation of China (No. 51574275).

REFERENCES

Bratton, T., Edwards, S., Fuller, J., Murphy, L., Goraya, S. & Harrold, T., et al. 2001. Avoiding drilling problems. Oilfield Review, **13**(2):113- 118.

Skogdalen, J.E. & Vinnem, J.E. 2012. Quantitative risk analysis of oil and gas drilling, using deepwater horizon as case study. Reliability Engineering & System Safety, **100**(100): 58 -66.

Abimbola, M. & Khan, F. 2016. Development of an integrated tool for risk analysis of drilling operations. Process Safety & Environmental Protection, 102, 421 -430.

Brandsæter, A. 2002. Risk assessment in the offshore industry. Safety Science, **40**(1): 231 -269.

Irrgang, R., Irrgang, H., Kravis, S., Irrgang, S., Thonhauser, G. & Wrightstone, A., et al. 2001. Assessment of risk and uncertainty for field developments: Integrating reservoir and drilling expertise.

Udegbunam, J.E. 2015. Improved well design with risk and uncertainty analysis. University of Stavanger Norway.

Lerche, I. 2012. Geological risk and uncertainty in oil exploration. Academic Press.

Sadiq, R., Husain, T., Veitch, B. & Bose, N. 2003. Evaluation of generic types of drilling fluid using a risk-based analytic hierarchy process. Environmental Management, **32**(6): 778 -787.

Hong-Bo, J.I., & Jiang, J.L. 2008. Hierarchical-analytic-method-based risk prediction of wellbore collapse and stuck pipe. Journal of Oil & Gas Technology.

Yuan, Z., Wang, H.G., & Hai-Qiang, P. 2010. Application of fault tree analysis to risk assessment of lost circulation hazards in drilling. China Safety Science Journal, **20**(3): 107- 112.

Khakzad, N., Khan, F. & Amyotte, P. 2013. Quantitative risk analysis of offshore drilling operations: A Bayesian approach. Safety Science, **57**(57): 108- 117.

Zhichuan, G., Kai, W., Fu, S. & Tingfeng, Z. 2013. Risk evaluation method for drilling engineering based on interval analysis. Petroleum Drilling Techniques, **41**(4): 15 -18.

Zhichuan, G., Tingfeng, Z., Yanan, S. & Kai, W. 2015. Research on method of discriminating drilling risk degree in complex formations. Oil Drilling & Production Technology, **11**(3): 14 -22.

Guang, S.I., Wei, L.H., Huang, W.H., Guo, Z. & Chen, Y.Y. 2009. The main influencing factors on the drilling cost and the corresponding controlling measures. Natural Gas Industry, 29(9): 106- 109.

Wang, Y., Yang, T., Zhang, G. & Zhang, S. 2010. Structure, influential factors, and control of cost of prospecting well. China Petroleum Exploration.

Leslie, J.C. 2007. The use of composite materials increase the availability of oil and gas and reduce the cost of drilling and production operations. Proceedings of SPIE - The International Society for Optical Engineering, 65310E-65310E-14.

Sharer, J.C. & Kenney, C.M. 1983. Strategic use of E-Discovery Counsel to manage risk and cost. The Strategic management handbook. McGraw-Hill.

Jian, Y.Y. 2002. Research on cost management of petroleum drilling. Tianjin Institute of Finance and Economics.

Austin, E.H. 1983. Drilling engineering handbook. Springer Netherlands.

Submitted: 27/10/2016
Accepted : 26/12/2016