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Risk Assessment of a Gas Well Test in the South China Sea Based On Fault Tree Analysis

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Abstract
Deepwater gas well testing in the South China Sea is characterized by high difficulty, high investment and high risk. In order to reduce effectively the risk of the gas well testing operation in the South China Sea, the potential risk factors in the South China Sea deepwater testing operation were analyzed and 42 categories of risk factors were identified. The fault tree analysis method was used to establish the fault tree model for a deepwater testing operation in a South China Sea gas well, and analyze the inter restricted relationship between risks. Combining with the hierarchical analysis method to calculate the weight values of the risk evaluation indicators and use the product of it with probability importance as the corrected value for the probability of occurrence of the basic event in the fault tree model, the fault tree analysis was performed to determine the probability of occurrence of the top-level event. The results of the study help reduce the risk of accidents in deepwater gas well testing operations and can inform the management of deepwater gas well testing sites.

Keywords: Fault Free Analysis; Test operation; Risk factor; Risk assessment.

Introduction

Due to the increasing difficulty and cost of onshore oil and gas wells, the exploitation of oil and gas worldwide is gradually shifting to the oceans, especially to the deepsea. The waters of the South China Sea belongs to one of the four major marine oil and gas enrichment areas in the world, with huge reserves of oil and gas resources [1,2]. As a necessary means of deepwater oil and gas resources exploration and development, deepwater oil and gas well testing is also one of the key links of deepwater oil and gas exploration and development. Moreover, not only reliable data resource results for the evaluation of tectonic and containment, but also the direct basis for efficient exploitation of oil and gas reservoirs was provided by the deepwater oil and gas well testing[3]. However, deepwater testing is characterized by high difficulty, high investment and high risk, so one of the key method to prevent the occurrence of major accidents in deepwater oil and gas well testing is to conduct risk analysis [4,5] and control. At present, studies on deepwater testing operations mainly focus on the suppression of natural gas hydrates during testing [6,7], prediction of wellbore temperature pressure field [8,9], study and optimization of mechanical behavior of test tubes and columns [10-12], and surface process modular design and process flow [13-15], which present a lack of risk analysis studies on deepwater gas well testing operations.

Based on this, the potential risk factors of the South China Sea deepwater testing operation were analyzed and 42 categories of risk factors were identified. The fault tree analysis method was used to establish the fault tree model for a deepwater testing operation in a South China Sea gas well, and analyze the inter restricted relationship between risks. Combining with the hierarchical analysis method to calculate the weighting value of the risk evaluation index, and use the product of it with the probability importance as the corrected value of the basic event occurrence probability in the fault tree model, the fault tree analysis was conducted to determine the occurrence probability of the top-level event, in order to effectively reduce the risk of a gas well test operation in the South China Sea, and provide a reference for deepwater gas well test site management.

1. Deepwater testing risk factor identification

1.1 Analysis of key risks

During the testing of deepwater gas wells in the South China Sea, the shallow geological hazards that affect operational safety are mainly shallow gas, shallow flow and natural gas hydrates, etc. Among them, natural gas hydrates are one of the main factors that cause geological hazards in deepwater areas. During the process of the deep water testing, natural gas hydrates are easily to be formed in the test column due to the influence of external temperature. Once the test column is blocked by the hydrates, the test operation will be suspended and no strati graphic data can be obtained [9,10]。 At the same time, the decomposition of natural gas hydrates may lead to submarine landslides and the released gas may lead to fire. Moreover, natural gas hydrates have potential to the blockage of the pipeline causing major accidents [16,17].

In addition, harsh marine environments such as typhoons, currents and waves have a great impact on the process of deep water testing operations. Typhoons may cause the shifting of platforms, making the deep well test column especially above the mud line is subject to a variety of load coupling, which cause great difficulties to the design and the safety control of the deep well test column. The process of deepwater surface testing is limited by the space of the drilling platform, which is prone to sudden accidents such as ice blockage on the ground and seriously threatens the testing operations [3]. At the same time, the huge waves formed by typhoons can cause damage to the platform, the overall collapse and other accidents. When the sea current has high velocity, it will severely affect the operation of the bulkhead, resulting in a large deflection of the platform and even forming serious operational accidents[18].

1.2 Risk identification and segmentation

For the deepwater testing operation of a gas well in the South China Sea, the risk of the deepwater testing operation was divided into three risk evaluation units through the analysis of the main risk factors: well condition and environmental risk, wellbore and equipment failure risk as well as operation and management risk. This research identifies 42 types of risk factors for the deepwater testing operation and forming the risk evaluation index system for the deepwater testing operation of a gas well in the South China Sea, as Figure 1 shows.

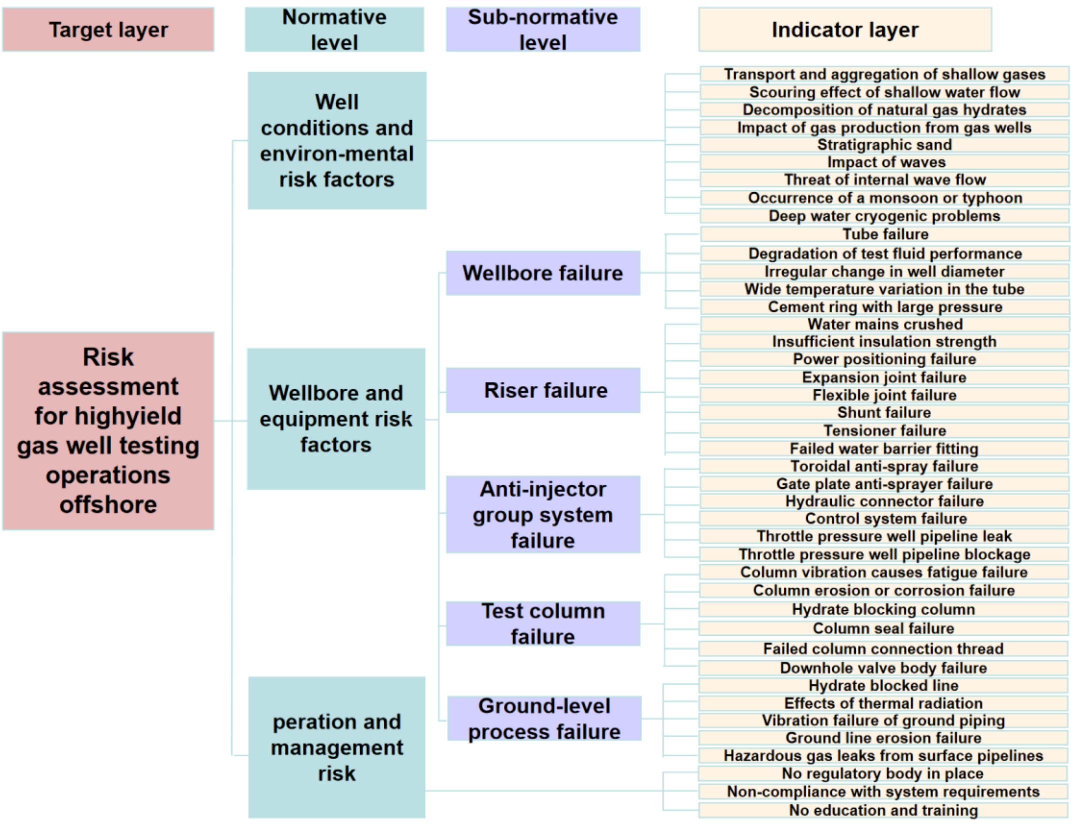

Fig.1 Risk Evaluation Index System for Deep Water Gas Well Testing Operation in South China Sea

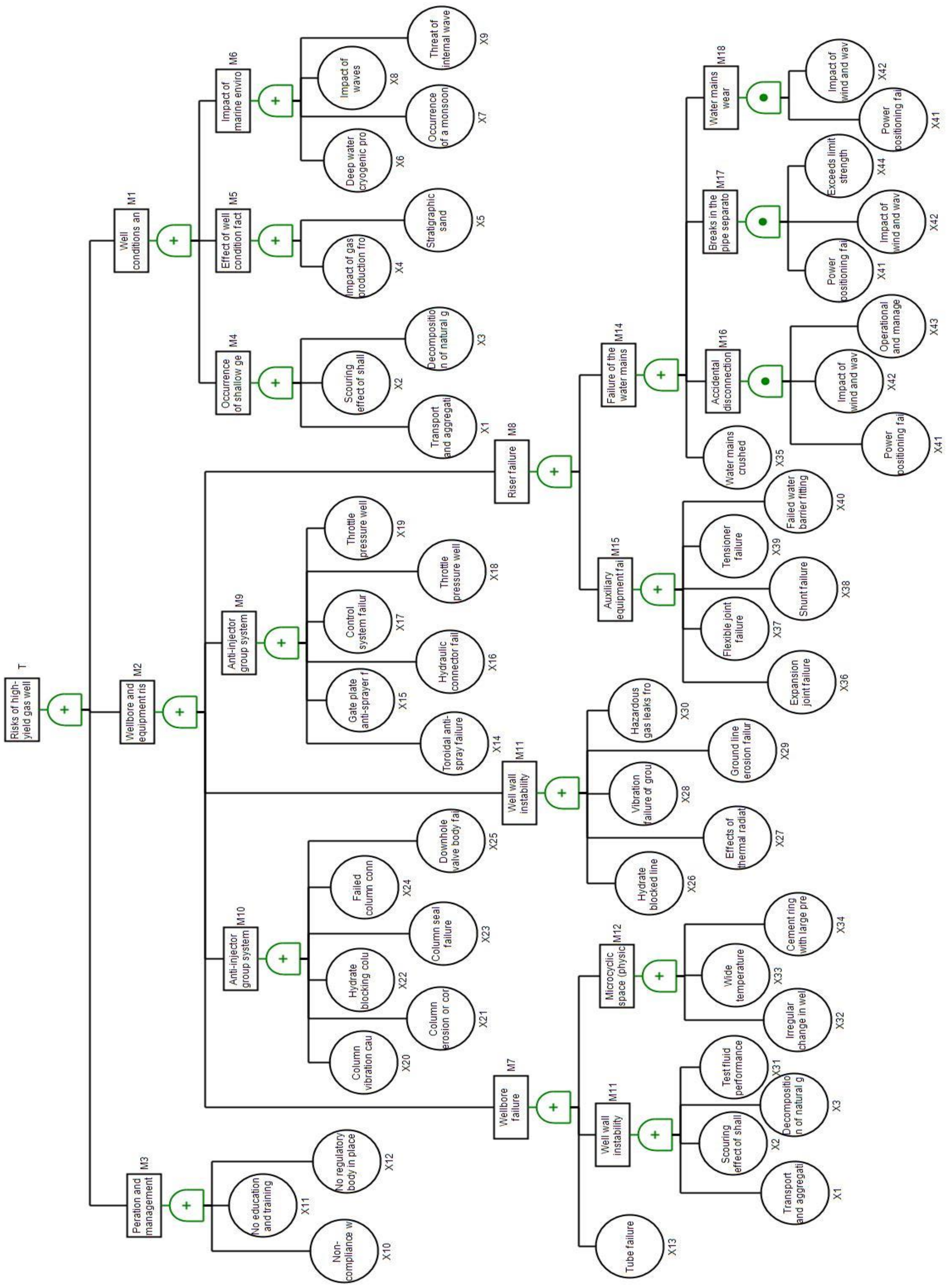

Fig.2: Fault tree model of Deep-Water Gas Well testing Operation in South China Sea

2. Construction of inter-risk constraints

There are many risk factors for deep water testing operations and the inter restricted relations among the risks. Based on the identified risk factors of the main test operation, the fault tree analysis method [19] was used to further analyze the restrictive relations among the risk factors and the fault tree model of a deepwater test operation of a gas well in the South China Sea was established, which is shown in Figure 2.

3. Case study

Based on the established fault tree model of a deep water gas well test operation in this paper, the risk assessment is carried out by taking a gas well test operation in deep water South China Sea as an example. During the process of quantitative analysis of the fault tree, considering the difficulty of collecting comprehensive statistics at the test site, this paper combines the hierarchical analysis method to calculate the weights of each evaluation risk indicator and multiply them with the product of probability importance as the corrected probability of occurrence of the underlying event for the fault tree analysis. From the field information, it is known that the well is located in the northeast of the Ledong Depression in the Southeast Qiong Basin, on the northwest branch of the South China Sea cyclonic circulation and anti cyclonic circulation. The water depth in this block ranges from 840 m to 1030 m, with an average temperature of 26.0°C, a maximum wind speed of 80 km/h and an average wind speed of 25 km/h; the wave height is concentrated in the range of 0 to 6 m, with a maximum wave height of 17 m and an average wave height of 3 m; no sea ice. In addition, the ocean flow field and other marine environmental variables in the region are characterized by significant seasonal variability, with the average monthly velocity of the surface current being 0.3 m/s during the winter northeast monsoon (October to February) and decreasing with increasing depth. The operating block ocean internal waves occur with high frequency in summer and autumn and low frequency in spring and winter, but occur with greater energy. All of this would seriously threaten the safety of deep water gas well testing operations.

3.1 Calculation and correction of the basic event probability of the incident tree

Hierarchical analysis is performed based on the established system of risk evaluation indicators for deep water testing operations. Take the target layer "a gas well test risk assessment in the South China Sea" as an example, the relative importance score of each risk evaluation indicator for a gas well test risk assessment in the South China Sea is obtained scored by field staff or experts, as Table 3-1 shows. From it, the risk assessment objective hierarchy analysis of a gas well test operation in the South China Sea is shown in Table 3-2. Similarly, the judgment matrices of the criterion and sub-criterion layers in the hierarchical model are constructed, and the normalized synthetic weights of each risk evaluation indicator in the indicator layer relative to the target layer are calculated. Therefore, the probability of occurrence of the underlying event in the fault tree model is determined and corrected, which is shown in Table 3-3.

Table3-1: Relative importance scores of risk assessment indicators

Risk evaluation indicators	Operational and management risks	Wellbore and equipment failure risk	Well conditions and environmental risks
Operational and management risks	1	9	6
Wellbore and equipment failure risk	1/9	1	1/3
Well conditions and environmental risks	1/6	3	1

Table3-2: Analytic hierarchy process of the target layer for risk assessment of test operations

Target layer	Judgment matrix	Parameter name	Parameter value	Normalization vector
G	$\begin{bmatrix} 1 & 9 & 6 \\ 1/9 & 1 & 1/3 \\ 1/6 & 3 & 1 \end{bmatrix}$	Maximum eigenvalue λ_{max}	3.05 36	0.77 03
		Stochastic consistency indicators R_I	0.58 00	0.06 79
		Stochastic consistency indicators C_I	0.02 68	
		Consistency ratio C/R	0.04 62 $<$ 0.1	0.16 18

Table3-3: Probability of basic events in thefault tree

Incident number	Basic Event Name	Probability of Occurrence	Correction probability

X1	Transport and aggregation of shallow gases	0.13 06	0.05 1104
X2	Scouring effect of shallow water flow	0.03 27	0.01 1501
X3	Decomposition of natural gas hydrates	0.04 00	0.01 4176
X4	Impact of gas production from gas wells	0.18 02	0.07 4783
X5	Stratigraphic sand	0.08 16	0.03 0225
X6	Deep water cryogenic problems	0.01 77	0.00 6130
X7	Occurrence of a monsoon or typhoon	0.02 49	0.00 8688
X8	Impact of waves	0.00 96	0.00 3298
X9	Threat of internal wave flow	0.25 30	0.11 5216
X10	Non-compliance with system requirements	0.09 95	0.03 7591
X11	No education and training	0.05 15	0.01 8473
X12	No regulatory body in place	0.01 07	0.00 3680
X13	Tube failure	0.00 16	0.00 0545
X14	Toroidal anti-spray failure	0.00 10	0.00 0341
X15	Gate plate anti-sprayer failure	0.00 19	0.00 0648
X16	Hydraulic connector failure	0.00 03	0.00 0102
X17	Control system failure	0.00 19	0.00 0648
X18	Throttle pressure well pipeline leak	0.00 02	0.00 0068
X19	Throttle pressure well pipeline blockage	0.00 45	0.00 1538
X20	Column vibration causes fatigue failure	0.00 32	0.00 1092
X21	Column erosion or corrosion failure	0.00 07	0.00 0238
X22	Hydrate blocking column	0.00 32	0.00 1092
X23	Column seal failure	0.00 03	0.00 0102
X24	Failed column connection thread	0.00 03	0.00 0102
X25	Downhole valve body failure	0.00 12	0.00 0409
X26	Hydrate blocked line	0.02 01	0.00 6979
X27	Effects of thermal radiation	0.00 70	0.00 2398
X28	Vibration failure of ground piping	0.00 70	0.00 2398
X29	Ground line erosion failure	0.00 32	0.00 1092
X30	Hazardous gas leaks from surface pipelines	0.00 11	0.00 0375
X31	Test fluid performance degradation	0.00 05	0.00 0170
X32	Irregular change in well diameter	0.00 05	0.00 0170
X33	Wide temperature variation in the tube	0.00 51	0.00 1744

X34	Cement ring with large pressure	0.00 05	0.00 0170
X35	Water mains crushed	0.00 12	0.00 0409
X36	Expansion joint failure	0.00 01	0.00 0034
X37	Flexible joint failure	0.00 02	0.00 0068
X38	Shunt failure	0.00 01	0.00 0034
X39	Tensioner failure	0.00 01	0.00 0034
X40	Failed water barrier fitting	0.00 01	0.00 0034
X41	Power positioning failure	0.00 04	0.00 0039
X42	Impact of wind and wave currents	0.28 75	0.00 0029
X43	Operational and management failures	0.16 17	0
X44	Exceeds limit strength	0.00 06	0

3.2 Determination of event probabilities at the top of the incident tree

Based on the established fault tree model of a gas well test operation in the South China Sea, the fault tree analysis is carried out according to the occurrence probability of the identifying basic events. The structure function of the fault tree shows as follows (1) :

T=M1+M2+M3=(M4+M5+M6)+(M7+M8+M9+M10+M11)+(X10+X11+X12)
=[(X1+X2+X3)+(X4+X5)+(X6+X7+X8+X9)]+[(X13+M12+M13)+(M14+M15)+(X14+X15+X16+X17+X18+X19)+(X20+X21+X22+X23+X24+X25)+(X26+X27+X28+X29+X30)]+ (X10+X11+X12)
=[(X1+X2+X3)+(X4+X5)+(X6+X7+X8+X9)]+{[X13+(X1+X2+X3+X31)+(X32+X33+X34)]+[(X35+X41*X42*X43+X41*X42*X44+X41*X42)+(X36+X37+X38+X39+X40)]+(X14+X15+X16+X17+X18+X19)+(X20+X21+X22+X23+X24+X25)+(X26+X27+X28+X29+X30)}+ (X10+X11+X12)
=X1+X2+X3+X4+X5+X6+X7+X8+X9+X10+X11+X12+X13+X14+X15+X16+X17+X18+X19+X20+X21+X22+X23+X24+X25+X26+X27+X28+X29+X30+X31+X32+X33+X34+X35+X36+X37+X38+X39+X40+X41*X42 （1）

From equation (1), it can be concluded that there are 41 minimum cut sets in this fault tree model, which are ：K1={X1}，K2={X2}，K3={X3}，K4={X4}，K5={X5}，K6={X6}，K7={X7}，K8={X8}，K9={X9}，K10={X10}，K11={X11}，K12={X12}，K13={X13}，K14={X14}，K15={X15}，K16={X16}，K17={X17}，K18={X18}，K19={X19}，K20={X20}，K21={X21}，K22={X22}，K23={X23}，K24={X24}，K25={X25}，K26={X26}，K27={X27}，K28={X28}，K29={X29}，K30={X30}，K31={X31}，K32={X32}，K33={X33}，K34={X34}，K35={X35}，K36={X36}，K37={X37}，K38={X38}，K39={X39}，K40={X40}，K41={X41，X42}

According to the formula for the probability of occurrence of top-level events by the least cut-off method, the probability of occurrence of top-level events in the fault tree can be calculated as follows ：

$$\begin{aligned} P(T) &= \sum_{i=1}^{k-1} q_i + q_{41}q_{42} - \left[\sum_{i=1}^{k-3} q_i\left(\sum_{j=i+1}^{k-2} q_j + q_{41}q_{42}\right) + q_{40}q_{41}q_{42}\right] + \cdots + (-1)^{k-1}\prod_{i=1}^{k+1} q_i \\ &= (0.051104 + 0.011501 + \cdots + 0.000034) + 0.000039 \times 0.000029 - \\ &\quad [0.051104 \times (0.011501 + \cdots + 0.000034 + 0.000039 \times 0.000029) + \\ &\quad 0.011501 \times (0.014176 + \cdots + 0.000034 + 0.000039 \times 0.000029) + \cdots + \\ &\quad 0.014176 \times (0.074783 + \cdots + 0.000034 + 0.000039 \times 0.000029) + \\ &\quad 0.000034 \times 0.000039 \times 0.000029] + \cdots + 0.051104 \times 0.011501 \times \cdots \times 0.000029 \\ &= 0.397899 - 0.141451 + \cdots + 5.1242 \times 10^{-120} \\ &\approx 0.337031 \end{aligned} \tag{2}$$

4. Conclusion

(1) By analyzing the main risks of the deepwater testing operation in the South China Sea, the fault tree analysis method was used to establish the fault tree model of the deepwater testing operation, forming an evaluation system of 3 evaluation units and 42 risk evaluation indicators for the risk assessment of the deepwater testing operation.

(2) A risk assessment of a gas well test operation in the South China Sea was carried out using a combination of hierarchical analysis and fault tree analysis, and the analysis calculated that the probability of occurrence for a top-level event was about 33.7%. Related research can help reduce the risk of deep water gas well testing operations in the South China Sea and provide references for site management of the deep water gas well testing.

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