SPE 141089

China Offshore Anti-collision Risk Management Standard and Remedial Measures

Cheng, Kun, SPE, Texas A&M U. Cheng, Zhong, CNOOC Energy Technology & Services Ltd., Wei, Yunan, C&C Reservoirs Inc., Wu, Wenyan, SPE, S.A. Holditch, SPE, Texas A&M U.

This paper was prepared for presentation at the SPE Americas E&P Health, Safety, Security and Environmental Conference held in Houston, Texas, USA, 21–23 March 2011.

Abstract

With the trend of economic, regulatory and technological changes, demand of a comprehensive standard to systematically evaluate and manage the risks of wellbore collisions has become significant in offshore oil development. Several accidents happened during normal operations at the Bohai Sea oilfield, including boreholes collision and drilling through adjacent casings. Under this situation, the China National Offshore Oil Corporation (CNOOC) adopted new offshore well anti-collision standard and related remedial measures.

As part of the anti-collision safety operation system in CNOOC offshore oil drilling, the standard is designed and established for requirements mainly in four perspectives, including: data and material collection specifications in the early stage of drilling; anti-collision risk analysis in drilling design; anti-collision safety technical measures in drilling operation and operation site; remedial strategies and operations in case of wellbore collision. In this paper, we also describe how the standard has been applied to the several recent cases, and discuss its benefits for the anti-collision risk control of drilling offshore cluster wells and adjustment wells, treatment cost reduction, and marine environment safety.

Introduction

With the worldwide growth in offshore drilling activities, operators are encountering more complicated and more crowded drilling, and greater emphasis is placed on avoiding collisions with offset wellbores. In China, there has been great development in offshore oil with a few significant trends:

- Increased complexity of drilling technologies: mature technologies include shallow orientation technology, wellbore controlling technology, and highly-deviated well sliding technology.
- Expanded project scope and costs in offshore applications: for example, there is great demand of large-scale development of Bohai offshore region in a short term, and, usually, the offshore platforms with ambitious drilling projects tend to increase the number of available slots without the expense of major additions to infrastructure. Coupled with an already crowded environment of existing wells, the need to add new ones to extend platform life creates very challenging collision-avoidance scenarios.
- Greater well density and well pattern: with the support of mature technologies and the need of expanding offshore oil development, the well pattern increases from 2×2 or 4×4 to 5×7 or 4×10, and the well spacing changes from 2m×2m to 1.8m×1.8m, or even smaller 1.5m×1.6m.

On one hand, these trends greatly reduce comprehensive cost of cluster well, improve the platform utilizing rate, and increase the oil field development speed; On the other hand, however, implications of well collisions are becoming significant: many wells are drilled in close proximity to each other, making the cross-borehole and collision problems quite possible under the conditions of crowded directional wells. Therefore, it is critical to establish comprehensive, reliable and effective anti-collision risk management standard and remedial measures for China offshore drilling.

For the crowded cluster wells, there are mainly three types of anti-collision problems:

- Anti-collision between wells in the platform, including the inclination of straight well intervals, the depth at the kick off point, and the initial orientation.
- Anti-collision between wells in the platform and prospecting wells in the field covered by the platform.
- Anti-collision between wells in the platform and wells in the nearby platforms.

In following sections, the paper analyzes two cases of borehole collisions. Then based on a thorough investigation and evaluation of the existing and potential problems as well as their consequences, it generalizes the experiences and lessons of CNOOC regarding the anti-collision issue. Finally, the paper describes the anti-collision risk management standard and remedial measures for offshore drilling in detail.

Case 1

The wells on the platform A in a Bohai Oilfield are distributed as 4×5 at the interval of 2m×1.8m. For the drilled wells, the borehole trajectory is shown in **Fig. 1**. The well A17h is the impending drilling well, and deviational survey data of A10h is recorded as in **Table 1**.

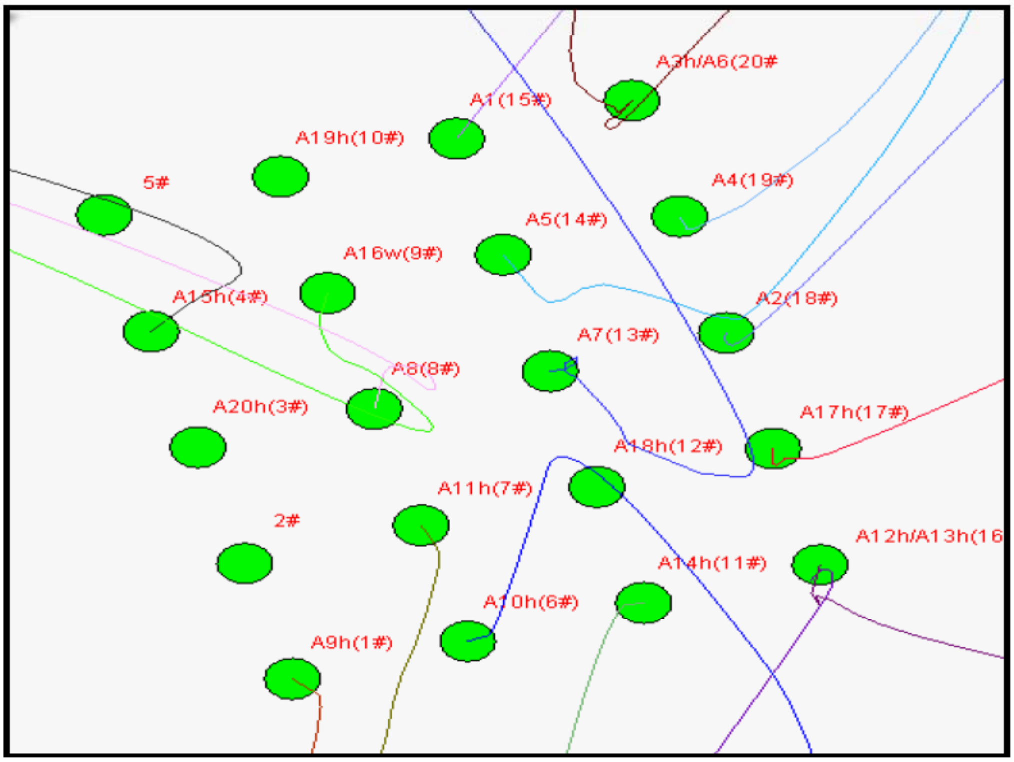

Fig. 1— Borehole trajectory of drilled wells.

TABLE 1— Well A10h statistical deviational survey Data

	MD (m)	CL (m)	Inc (°)	Azi (°)	TVD (m)	N/S (m)	E/W (m)	V.Sec (m)	Dogleg (°/30m)	T.Face (°)	Build (°/30m)	Turn (°/30m)
1	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.000	0.000
2	70.00	70.00	0.37	69.40	70.00	0.08	0.21	-0.13	0.159	69.40	0.159	0.000
3	90.00	20.00	1.21	14.20	90.00	0.31	0.32	-0.38	1.566	-72.12	1.260	-82.800
4	110.00	20.00	1.58	15.20	109.99	0.78	0.45	-0.87	0.556	4.26	0.555	1.500
5	130.00	20.00	1.77	12.30	129.98	1.35	0.59	-1.45	0.312	-25.50	0.285	-4.350
6	150.00	20.00	1.71	15.00	149.97	1.94	0.73	-2.06	0.152	127.54	-0.090	4.050
7	170.00	20.00	1.83	10.70	169.96	2.54	0.87	-2.67	0.268	-50.06	0.180	-6.450
8	195.50	25.50	2.31	132.59	195.46	2.59	1.32	-2.84	4.266	147.24	0.565	143.400
9	234.49	38.99	7.70	150.60	234.28	-0.22	3.18	-0.60	4.270	25.37	4.147	13.857
10	253.69	19.20	8.90	174.70	253.29	-2.82	3.95	1.72	5.700	83.16	1.875	37.656
11	273.71	[illegible]	10.20	158.30	273.03	-6.01	4.75	4.60	4.498	-72.70	1.948	-24.575
[illegible]	[illegible]	[illegible]	[illegible]73	165.44	312.25	-12.88	6.99	10.68	1.053	71.31	0.399	5.371
[illegible]	[illegible]	[illegible]	[illegible]12	169.09	327.28	-15.71	7.63	13.25	1.557	62.39	0.765	7.157
[illegible]	[illegible]	[illegible]	[illegible]07	175.82	355.94	-21.53	8.38	18.69	1.693	58.25	0.974	6.900

measured data by GYRO

Influenced by offset wellA11h and wellA14h, azimuth measured by MWD has diviation.

Anti-collision scanning data of the well A17h and well A10h is indicated in **Table 2**.

TABLE 2— Anti-collision scanning data for well A10h and well A17h

Measured Depth (m)	Vertical Depth (m)	Measured Depth (m)	Vertical Depth (m)	Reference (m)	Offset (m)	Highside Toolface (°)	Offset Wellbore Centre +N/-S (m)	Offset Wellbore Centre +E/-W (m)	Between Centres (m)	Between Ellipses (m)	Maximum Separation (m)	Separation Factor
190.00	189.96	189.95	189.94	0.34	0.33	-31.27	2.73	3.57	2.40	1.73	.67	3.585
200.00	199.95	199.94	199.94	0.36	0.35	-55.48	2.73	3.63	2.19	1.49	.70	3.113
210.00	209.93	209.92	209.92	0.38	0.37	-77.36	2.73	3.70	2.00	1.26	.74	2.711
215.81	215.72	215.73	215.73	0.39	0.38	-92.15	2.70	3.72	1.97	1.21	.76	2.589 CC, ES
220.00	219.89	219.92	219.92	0.40	0.38	-103.36	2.65	3.72	1.99	1.22	.78	2.562 SF
230.00	229.83	229.87	229.87	0.42	0.40	-129.44	2.49	3.72	2.36	1.54	.82	2.885
240.00	239.74	239.80	239.80	0.44	0.42	-154.37	2.34	3.71	3.24	2.39	.85	3.801
250.00	249.64	249.72	249.71	0.47	0.44	-172.86	2.18	3.70	4.45	3.57	.88	5.036

Based on the analysis of ant-collision scanning data, the distance between the two wells is 1.97m and separation coefficient is 2.589 at the depth of 215.81m. The two wells gradually separate from each other below the depth with no collision risk in the following well intervals.

The well A17h began to slide and build angle from the depth of 224m, and when the slide drilling arrived at the depth of 229.4m, the pumping pressure increased by 50-100 psi with drilling pressure by 1-2T, and the mechanic drilling speed reduced to 8-12m/h. There was an observation about abnormal parameters when the continuing slide drilling arrived at the depth of 229.6m. Parameter variation is shown in **Fig. 2**.

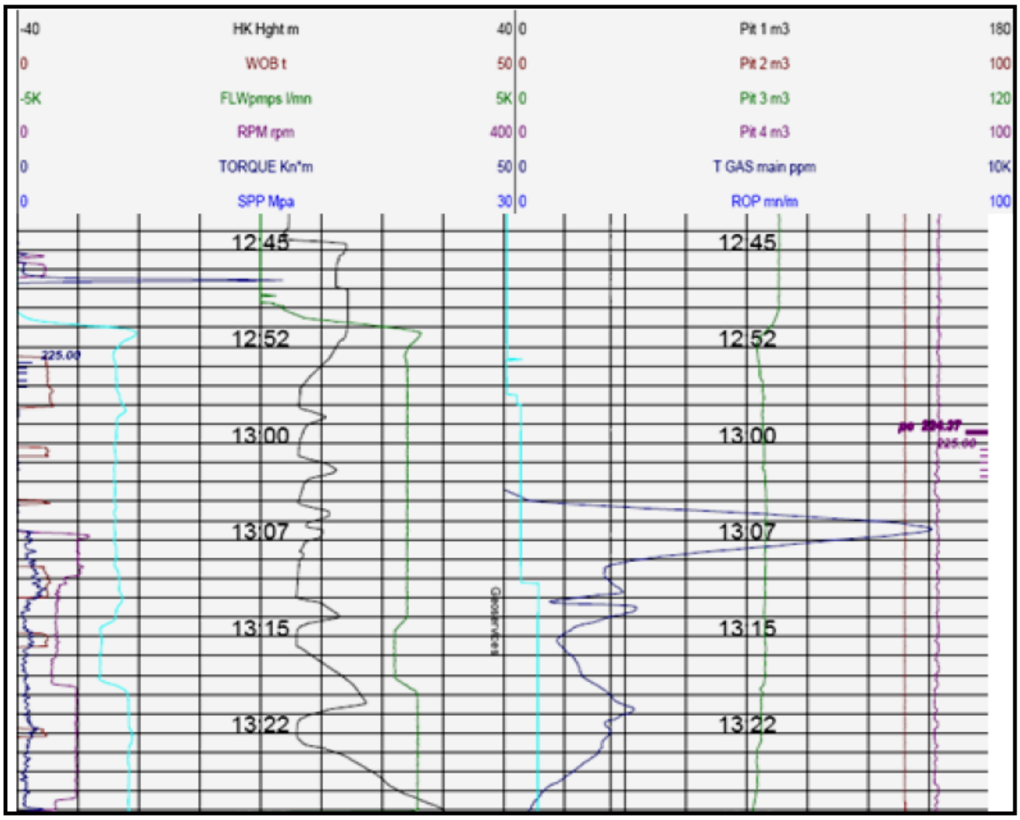

Fig. 2—Drilling parameters variation of Well A17h.

According to the results of anti-collision scanning software, there was no data indication of collision between the well A17h and its offset wells. Therefore, it was decided to use rotary drilling for the followed drilling. When the rotary drilling reached at the depth of 229.8m, the operator discovered that there was return of drilling mud between the casing 13-3/8" and casing 9-5/8" in the well A10h, and there was no change for the liquid level of the casing 9-5/8". Then the PDC drilling bit was tripped out and examined. As the edging teeth of the bit were grounded, it was confirmed that the well A17h was penetrated into the casing 9-5/8" of well A10h.

Results Interpretation

- There was severe inclination on the surface. The straight intervals of well A10h inclined greatly, and, in particular, to the internal slots. The straight well intervals all inclined to the degrees between 1.6°and 2.1°, and to the North of 3.42m and the South of 0.87m for the trajectory at 195m.
- The measurement tools and trajectory data generated elliptical error. There are a few measurement tools, including ESS, GYRO and MWD. As the data measured by these tools all have systematic errors to different degrees during the measurement process, there is deviation between the calculated borehole trajectory and practical trajectory. When the interval between the measurement points is too large, it causes errors in the real borehole trajectory.

Case 2

In Bohai Sea oilfield, platform C had 4×5 slot structure and 1.8m×2m spacing. 14 wells were drilled as shown in **Fig. 3**. It also can be seen that well C19h had serious collision risk. There were 7 drilled wells around well C19h and 4 out of 7 wells' kick off points were shallower than well C19h's. Therefore, before drilling well C19h we designed a detailed anti-collision and bypassing barrier plan as demonstrated in **Fig. 4**.

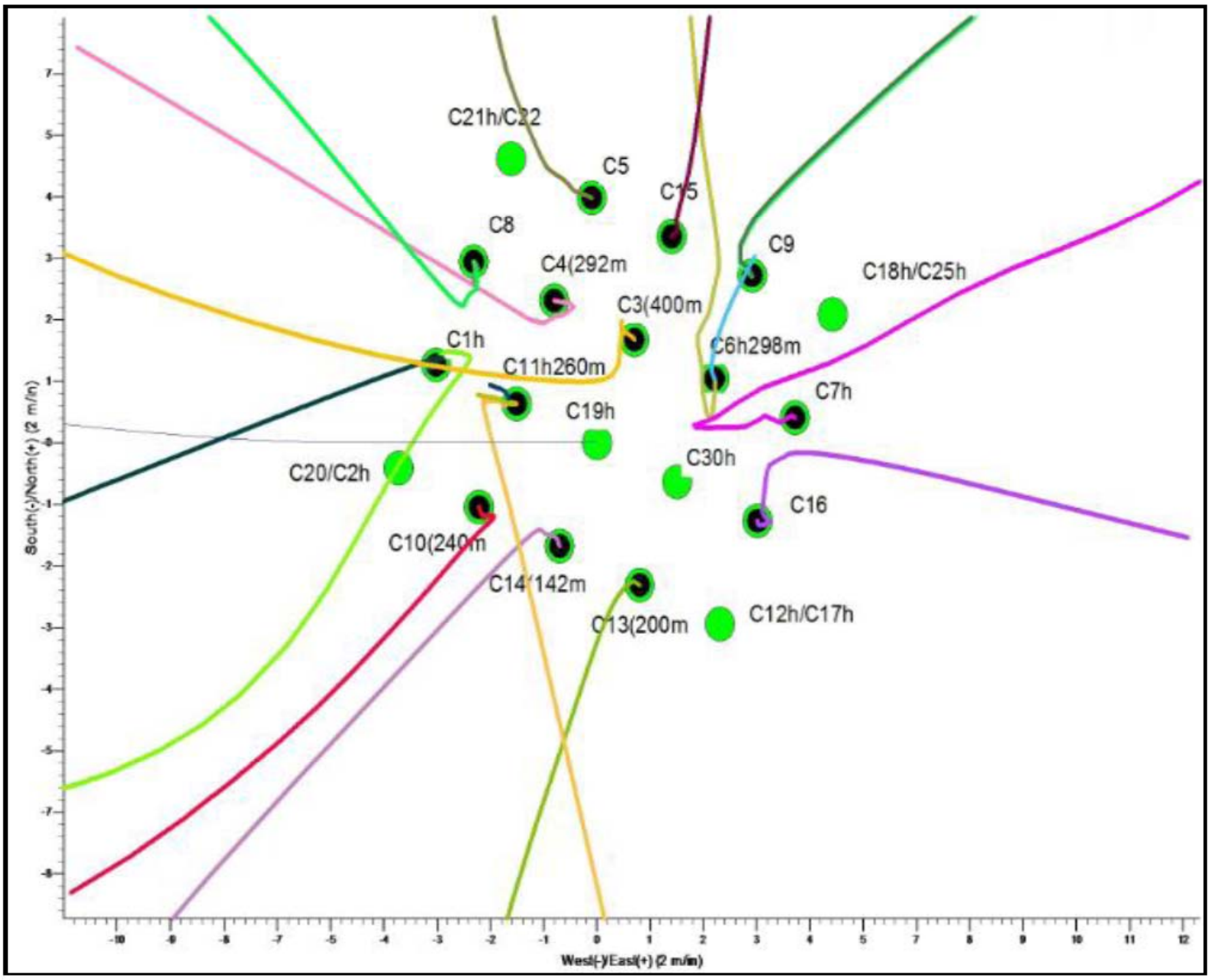

Fig. 3-Drilled wells' wellbore trajectory on platform C

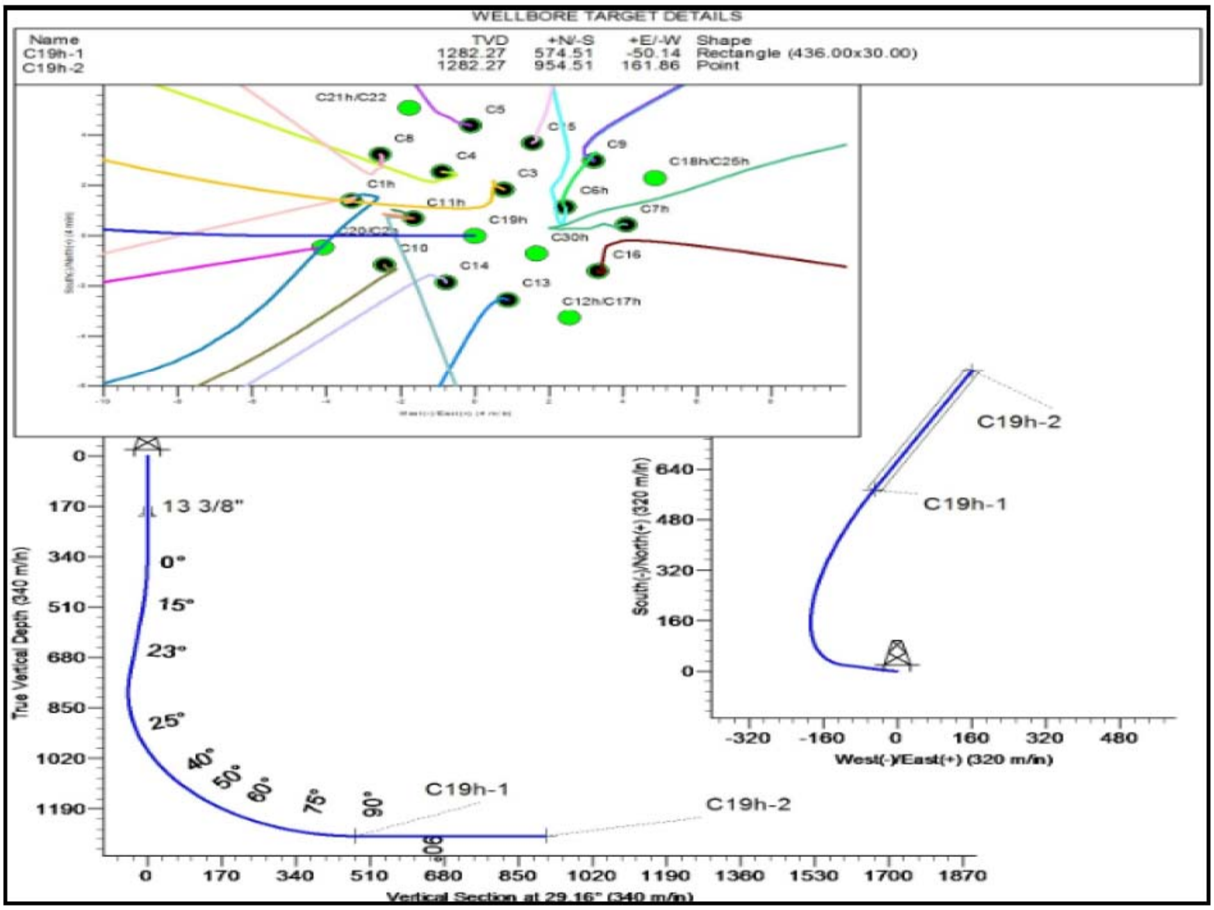

Fig. 4-Anti-collision and bypassing barrier plan for well C19h.

According to old CNOOC anti-collision risk management standard, operators used cone rock bit for drilling. When wellbore 12-1/4" was drilled to 335.7m, torque increased from 1.5kn.m to 2.5kn.m, pumping pressure from 9.7Mpa to 10.2Mpa, and fluid volume was 3800L/min. The operators tripped out immediately and discovered that gas content increased quickly. Then BOP was closed. Finally, Technician confirmed that drilled well C11h casing pressure decreased. Drilling parameters were recorded in **Fig. 5**.

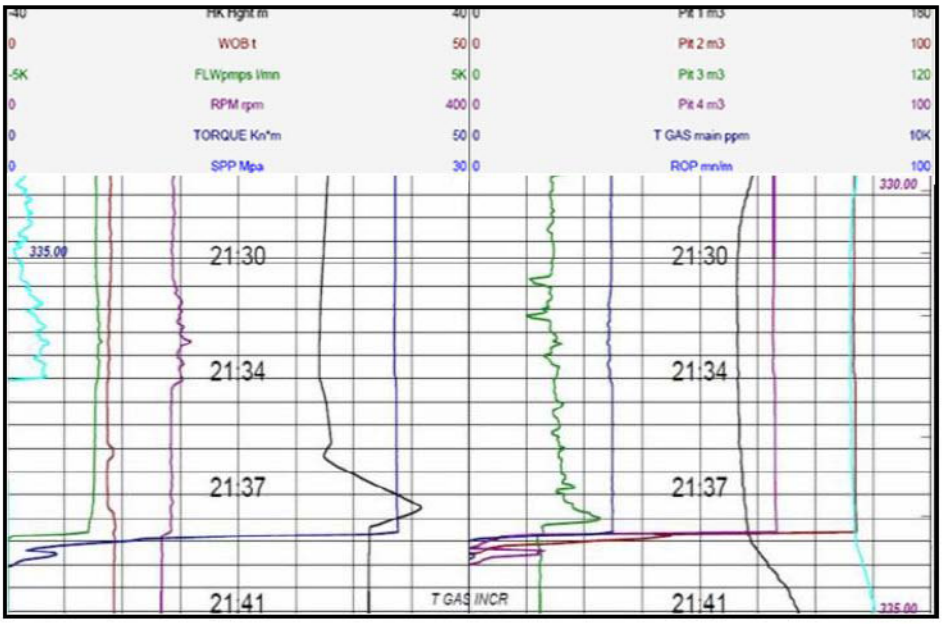

Fig. 5-Well C19h drilling parameters records.

Results Interpretation

Before operation, we realized that well C19h would have serious collision risk and made detailed anti-collision and bypassing barrier plan, but operators penetrated well C11h's casing eventually. After analyzing the results, we found 2 main interpretations as follows:

- There was no trajectory data for well C19h from 0 to 211.56m. Operator treated this section as a vertical well section to proceed anti-collision scanning.
- When drilling wellbore 12-1/4" of well C19h in shallow layer, MWD encountered magnetic interference which caused gyro could not analyze trajectory direction.

Anti-collision Risk Management Standard and Requirement

After describing and analyzing 2 cases, we realize that the old CNOOC anti-collision risk management standard only regulates the on-site operations. However, the old standard is not appropriate for the anti-collision management of crowded cluster directional drilling. Consequently, the incomplete old anti-collision risk management standard could lead to several potential issues, including:

Delayed modification for the general anti-collision design. To develop Bohai Sea oilfield, we adopt effective drilling and production technology strategy based on exploration data to make a plan for drilling and producing operations at early stage. In the drilling process, we evaluate the well once it is drilled, which helps us better understand the block resource distribution. According to the evaluation data, we adjust well pattern to optimizing production strategy. However, this technical mode leads to a frequent well design modification and further increase the collision risk when drilling crowded cluster directional well. As a result, the inconsistency between the general anti-collision design modification and on site operations may possibly cause disastrous consequences.

Inaccurate or unavailable trajectory data for existing wells. Inaccurate or unavailable trajectory data is the main reason that leads to failure of anti-collision plan for Case 2. Case 1 demonstrates that data density can also influence anti-collision design and operation, if it is not enough to reflect the actual offset well trajectory.

Lack of safety awareness. The other main reason causing wells collision is that operators or technicians do not have enough experience and lack of safety awareness. Insufficient communication between onshore office and offshore site can negatively affect the implement of anti-collision plan.

Against the above problems, the CNOOC improves and completes the offshore drilling anti-collision standard and related remedial measures. For the improved standard, it emphasizes the anti-collision risk management of crowded cluster directional drilling from two aspects: static anti-collision (i.e., anti-collision considerations in design) and dynamic anti-collision (i.e., anti-collision requirements in practical drilling). The detailed requirements are as follows:

Static anti-collision: optimize the overall crowded cluster well drilling plan and single well plan.

- Slot arrangement and distribution. To avoid man-made wells intersect and decrease anti-collision operation difficulty, the platform jacket should be installed according to drilling operation steps. Before starting well spacing, operator also needs to consider well inclination. Wells having higher angle of inclination use outside slots and wells having lower angle of inclination use the inside ones. Further we try to avoid azimuth crossed in the same slot line at the same depth.
- Kick off point selection. In principle, Kickoff point should be in the homogenous layer with good drillability. To lower reduce well the inclination angle at the hold angle section, the depth of crowded cluster wells' kickoff points should be shallow. The depth of kickoff points should be gradually deeper from the boundary wells to wells at the center part. Simultaneously, operators should consider avoiding horizontal magnetic interference.
- To lower wells collision risk, pre-deviation plan should be adopted for marine riser and surface casing pipe.
- Drilling procedure meets the anti-collision principles. The directional wells with shallow kickoff points should be drilled at the very first. Then ones with deep kickoff points can be drilled. Vertical wells are allowed to drill at the final step.
- Before operation, the offset wells' trajectory data should be acquired. For wells without available existing well trajectory data, the supplement measurements are necessary. In the process, use anti-collision software assists trajectory control. For the well sections causing collision risk, technicians must notify on-site operators to infill measurements to make sure results reflect practical situation. Then a large scale accurate anti-collision drawing can be draw. Meanwhile, single well design should consult the whole anti-collision plan to make spare conditions for following operations.
- Update and confirm anti-collision plan timely. Based on modified well position and anti-collision difficulty, the latest and optimized general and single well anti-collision plan must be made timely. Communicate with onshore

departments, especially the reservoir department, to minimize the operations for avoiding obstacles. After verifying the final design plan, the on-site operators must be notified timely.

Dynamic anti-collision: strength on-site and on-shore communication, improve approaches of controlling borehole trajectory, and concern well conditions changes closely.

- Improve the measurement of surface intervals, and for the wells at collision risk, the gyro must be used to measure the borehole trajectory. The reason is that most of straight well intervals' collision and drilling out casing accidents happen at depth around 250m to 600m. Therefore, to guarantee the data accuracy, gyro is required to double-check the trajectory data when the well deviation is less than 20°. Anti-collision and avoiding obstacles design is performed once the data is send back to the onshore office.
- Enhance the anti-collision management. To secure the drilling at casing shoe and succeed in directional drilling, it is appropriate to apply directional gyro to directional drilling, and then use MWD tool when there is no magnetic interference. The related operation regulations should be strictly implemented, and consistence of different data reference systems is required for gyro measurement. Besides, before drilling the last 5-8 wells gyro is needed to double-check the well trajectory data of offset wells.
- Optimize drilling parameters. The approach of light weight on bit (WOB) should be adopted, and the drilling speed should be controlled at straight well intervals, especially for sandwich sections.
- Pay close attention to the change of drilling parameters and returns of drilling mud. For the safety of offset wells, the cone bit should be chosen for direction at first. After confirmed, the PDC bit can be used for the further directional drilling. This is because that the main force of cone bit is press-in impact with small shear stress, which makes it easier to examine the downhole conditions and reduce the damage to casing. In contrast, due to its rock-breaking mechanism, the PDC bit has great harmful influence to the casing and makes the construction decision difficult. The main phenomenon of bolehole collisions are:
    1. Collide the casing when sliding drilling: under the conditions of constant pumping pressure, WOB does not reduce. Meanwhile, the rate of penetration (ROP) becomes lower;
    2. Collide the casing when rotary drilling: WOB increases, ROP becomes lower, and torque changes greatly;
    3. B total value of MWD is beyond the normal values;
    4. Cement content in mud returns is high. There are even iron scraps in mud returns under highly serious conditions;
    5. There is impact sound in the offset well's well head. In case of such situations, the pump should be immediately closed and pulled off the bottom, in combination with other proper treatment measures.
- Effectively communicate and make arrangement with operators. To guarantee the smooth implementation of anti-collision operation, warnings and instructions for the present anti-collision risks should be notified to operators. During the operation, in addition to directional-drilling technicians for 24-hour continuous operation monitoring, drilling supervisors are needed to coordinate and arrange every service. Specifically, the arrangement is:
    1. At the drill floor, directional drilling engineers examine the WOB, ROP, and other parameters, and notify the drilling supervisors of the abnormal phenomenon;
    2. At the mud shakers and overhead tank, specific person is assigned to monitor rock cuttings, and notifies the drilling supervisors once observes iron scraps which needs mud engineers to reconcile and solve;
    3. Logging staff are included to bail out, check the rock cuttings, and inform the drilling supervisors of abnormal conditions.

Remedial Measures and Requirements

In accordance with the improved offshore anti-collision risk management standard, wellbore collision risk can be basically eliminated. However, because of subjective factors by operators or technicians, wellbore collision may happen when anti-collision plan cannot be effectively executed. Therefore, we need to make reasonable remedial measures.

If the collision happens during drilling process, appropriate wellbore collision remedial measures should be immediately started. Firstly, we must stop drilling and pick up drilling string. Then, we should determine the collision location. Sequentially, according to the actual collision situation we should make the appropriate remedial measures as follows:

Collide with production well

Notify the operator to shut down the submersible pump (ESP) immediately (stop injecting gas for gas lift wells), close ESP packer' release valve (close annulus packer's release valve), then the reservoirs' connectivity between penetrating position and packer can be cut off. At the same time, ask all the present staffs to extinguish all the possible ignition points and prepare for the emergency situation to prevent the potential health risk from toxic gas.

Penetrating casing causes different risks which need appropriate measures:

- Lost circulation: If the penetrating position is shallow, or packer failure with small reservoir pressure, drilling fluid may flow into production well's annulus causing lost circulation. At this time, operator should pay attention to keeping drilling wellbore fluid level. Through checking flowback, analyze the efficiency of production well's ESP packer (gas lift well's annulus packer) timely, prepare for well control, and report real-time situation to onshore base.

- Kick or blowout: Kick or blowout occurs when oil from offset well flows into drilling wellbore without effective packer. Once confirm the abnormal situation, soft shut-in is preferred. If formations have no leakage or the situation is very critical, hard shut-in is the only choice. Operators should immediately adopt well control program. It is also necessary to fully understand complex pressure system where production well reservoirs and shallow layers of drilling well are connected. Report real-time situation to onshore emergency office and perform the feedback instructions.
- Oil spill: After kick or blowout occurs, there is a risk to appear oil spill. If oil spill occurs in the drilling fluid circulation system, we need to control oil spill volume and recycle the spilled oil as soon as possible; if oil spill accident is caused by the high shut-in pressure (SIP) and layers leaking fluid at casing shoe, the emergency program must be initiated immediately.

Collide with injection well

Stop injecting or pumping, observe casing pressure and standpipe pressure trend of the collided well. Drilling fluid flowing into collided well annulus may display lost circulation phenomena, but this cannot lead to leakage because of disconnection between drilling well and collided well layers. After stabilizing pressure, trip and backfill cement plug.

Collide with abandoned prospecting wells

If the drilling wellbore collides with the abandoned prospecting wells, there is little chance to cause serious health, safety, and environment accidents. The main risk is sticking. It is possible that drilling wellbore sticks to abandoned prospecting wells at penetrating position. It is also possible that the sticking causes cement dribbling. Under above situations, operators should follow the normal procedure to deal with sticking.

Conclusions

This paper has outlined growing trends in the China offshore oil development and the various challenges of potential well collisions posed by the large-scale intense projects and crowded drilling activities. To be specific, the paper studied two cases of borehole collisions in Bohai Sea field and analyzed the survey data and measurement tools. Based on the recent experiences and lessons, the CNOOC noticed that the demand of effective risk assessment and anti-collision management can be expected to become more critical in the years ahead. Therefore, the CNOOC established the new offshore well anti-collision standard, which comprehensively and specifically regulated the requirements and recommendations to reduce the collision risk. It is also noted that the remedial measures concerning both the operation measures and operators is important to cope with different well-collision situations. Currently the new standard and measures have been successfully applied to the directional drilling of crowded cluster wells in Bohai Sea field, and been effective in the anti-collision management for multiple platforms.

References

China National Offshore Oil Corporation. 2009. Offshore Drilling Manual: 573-592.

Poedjono, B., Akinniranye, G., Conran, G., San Antonio, T., Phillips, W. 2007. Minimizing the Risk of Well Collisions in Land and offshore Drilling. Presentation SPE 108279 given at the SPE/IADC Middle East Drilling Technology Conference and Exhibition, Cairo, Egypt, 22-24 October.

Poedjono, B., Lombardo, G.J., Phillips, W. 2009. Anti-Collision Risk Management Standard for Well Placement. Presentation SPE 121040 given at the SPE Americas E&P Environmental & Safety Conference, San Antonio, 23-25 March.

Poedjono, B., Avila, C., Van, C.P., Isevcan, E., Walker, J., Gonzalez, L.F., McCulloch, S. et al. 2010. Case Studies in the Application of an Effective Anticollision Risk Management Standard. Presentation SPE 126722 given at the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Rio de Janeiro, Brazil, 12-14 April.

Sharma, N., McDonald, M., Mohammed, J., Daire, B., Eicks, T., Jew, L. 2009. Optimizing Directional Drilling While Minimizing the Risk of Well Collision in Offshore Drilling. Presentation SPE 124246 given at the SPE Annual Technical Conference and Exhibition, New Orleans, 4-7 October.