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Analysis and Design of Trial Well Mooring in Deepwater of the South China Sea

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Abstract: Mooring systems play an important role for semi-submersible rigs that drill in deepwater. A detailed analysis was carried out on the mooring of a semi-submersible rig that conducted a trial well drilling at a deepwater location in the South China Sea in 2009. The rig was 30 years old and had a shallow platform with a designed maximum operating water depth of 457 m. Following the mooring analysis, a mooring design was given that requires upgrading of the rig's original mooring system. The upgrade included several innovations, such as installing eight larger anchors, i.e. replacing the original anchors and inserting an additional 600 m of steel wires with the existing chains. All this was done to enhance the mooring capability of the rig in order for the rig to be held in position to conduct drilling at a water depth of 476 m. The overall duration of the drilling was 50 days and the upgraded mooring system proved to be efficient in achieving the goal of keeping the rig stationary while it was drilling the trial well in the South China Sea. This successful campaign demonstrates that an older semi-submersible rig can take on drilling in deep water after careful design and proper upgrading and modification to the original mooring system.

Keywords: offshore; anchor operation; mooring; chain; wire; chaser; drilling engineering; semi submersible; South China Sea; anchor handling vessel (AHV)
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1 Introduction

China's rapid economic development simply implies the need for more oil/gas consumption. Unfortunately, the domestic supply of oil/gas from both land and shallow offshore oilfields has been on the decline in recent years. A series of oilfields in deepwater areas located in the South China Sea have been discovered since 2006. These deepwater oilfields have shown good prospects of oil/gas reserves and some of them will begin producing oil/gas in 2013 according to the planned schedule. China Oilfield Services Limited is a large state-enterprise that has been providing services to offshore operations in the South China Sea. Despite owning a deepwater semi-submersible rig that is capable of operating in very deep water, it is also necessary to operate shallow water semi-submersible rigs in deeper water with enhancement to their original mooring systems. Therefore, a trial well was drilled to prove the possibility of shallow water semi-submersible rigs operating in deepwater after upgrading and modification to its mooring system.

It critical for the mooring system of a shallow water semi-submersible rig to be upgraded in order for it to be able to drill in deepwater. The 30 year old semi-submersible rig "Nanhai V" was selected for this trial. Although the rig had a designed maximum operating water depth of 457 m, it was able to drill in a water depth of 476 m for the trial well after proper modification to the mooring system.

The trial well in deepwater was conducted from March 28th to April 27th, 2009. The well is located 250 km east of Hainan, China, at a water depth of 476m. The coordinates of the well are as follows: latitude 18.7° and longitude 112.5° (Guo YF, 2010). The semi-submersible rig "Nanhai V" together with 3 AHVs, (all of which are from China Oilfield Services Limited), took part in the operation (Guo *et al.*, 2006).

2 Analyses on moorings

When analyzing the mooring system of the semi-submersible rig, the stresses and strains of each of the mooring lines were calculated and analyzed using "ROMEO" mooring analysis software. Information including metrological ocean data of the South China Sea (Frank Lim, 2007), bathymetry of the well site, and specifications of the rig were input into the program in order to generate the results. References to the standard of international ISO 19901-7(ISO 19901-7, 2005) were also made.

2.1 Metrological ocean data

Table 1 shows the metrological ocean data collected from the well location in the South China Sea (Meet Ocean Criteria, 2007).

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2.2 Basic physical modes

There are two physical modes or statuses of the semi-submersible rig when drilling with its mooring system; one is the operation mode and the other is the survival mode (API RP 2SK, 2005):

Table 1 Wave, monsoon, and current-NE monsoon

Return period	1- year	10- year
H_s /m	3.5	5.5
T_z /s	8.8	10.9
1-min wind /$(m{\cdot}s^{-1})$	15.8	20.5
1-hour wind /$(m{\cdot}s^{-1})$	12.9	16.8
Surf current /$(m{\cdot}s^{-1})$	0.30	0.60

(1) When the semi-submersible rig is in operation mode, the rig will carry out normal drilling and has a smaller drift. The regulations from the Det Norske Veritas (DNV) state that the maximum displacement of the semi-submersible rig is within 3.5% of the water depth in the operation mode. This means the drift of the rig cannot exceed 16 m during the trial well drilling operation;

(2) When the semi submersible rig is in survival mode, the rig is encountering monsoon or typhoon weather and it is at an abnormal status with the rig experiencing larger horizontal displacement. The regulations from the DNV state that the maximum displacement of the semi-submersible in the survival mode is within 7% of the water depth; therefore the drift of the rig will not be over 33 m during the trial well drilling operation.

2.3 Coefficient of damping of moorings

It is important to determine the coefficient of damping for analyzing the responses of the moorings. The coefficient of damping was ensured as 10% of the surge and 20% of the swing of the rig, which is in accordance with the data gathered from the rig "Nanhai V" in the South China Sea since 1986 (R.P.Della, 1987).

2.4 Loads and displacements on moorings

Both loads and displacement of moorings were calculated under various conditions, such as normal drilling in good weather and monsoon or typhoon conditions. There were many methods to be used, such as the quasi-static and dynamic methods. There were some special circumstances which are explained as follows (G. Breese 1988):

(1) In the monsoon conditions, the calculation of the loads on the moorings and therefore rig displacements were based on occurred ocean data where a monsoon was encountered once in 10 years, as shown in Table 2.

(2) In the typhoon condition, the calculation of the loads on the moorings and therefore rig displacements were based on occurred ocean data where a typhoon was encountered once a year, as shown in Table 3.

Table 2 Mooring line loads encountered monsoon once 10 years

Environment Heading	Cases	Failed Line No.	Environment Load	Rig Max tension		Rig Max offset		Anchor Intension	Anchor Uplift angle
			/t	/t	/%MBS	/m	/%WD	/t	/(º)
Quart (East)	intact		91	167	30%	15.8	3.33%	95	0
	failure	2	92	235	42%	37.4	7.87%	186	0
	failure	1	89	234	42%	37.4	7.87%	184	0
Heading (North-east)	intact		80	164	29%	16.3	3.43%	93	0
	failure	1	80	209	37%	35.4	7.45%	152	0
	failure	8	80	204	43%	35.4	7.45%	145	0
Quart (North)	intact		91	166	30%	15.5	3.26%	95	0
	failure	7	92	239	43%	36.4	7.66%	191	0
	failure	6	89	238	43%	36.1	7.60%	189	0
Beam (Northwest)	intact		103	177	32%	20.2	4.25%	109	0
	failure	7	102	228	41%	39.5	8.32%	177	0
	failure	6	102	230	41%	39.7	8.36%	178	0

Table 3 Mooring line loads encountered typhoon once a year

Environment heading	Cases	Failed line No.	Environment load	Rig max tension		Rig max offset		Anchor intension	Anchor uplift angle
		.	/t	/t	/%MBS	/m	/%WD	/t	/(º)
North (quart)	intact		274	228	41%	47.0	9.89%	175	0
	failure	8	256	367	66%	73.0	15.37%	332	3.8
	failure	7	254	368	66%	73.3	15.43%	331	4
Northwest (beam)	intact		263	219	39%	50.5	10.63%	164	0
	failure	6	253	296	53%	77.4	16.29%	260	0.6
	failure	7	249	293	52%	76.4	16.08%	256	0.5
West (quart)	intact		275	229	41%	47.8	10.06%	476	0
	failure	5	256	369	66%	73.8	15.54%	332	4.0
	failure	6	255	365	65%	74.3	15.64%	327	4.1
Southwest (quart)	intact		227	201	36%	46.7	9.83%	140	0
	failure	4	227	270	48%	75.5	15.89%	229	0
	failure	5	227	263	47%	74.9	15.77%	220	0
South (quart)	intact		274	227	41%	50.4	10.61%	173	0
	failure	3	255	365	65%	77.6	16.34%	325	4.8
	failure	4	256	362	65%	77.7	16.36%	321	4.8
Southeast (Beam)	intact		263	218	39%	53.6	11.28%	161	0
	failure	2	249	286	51%	80.5	16.95%	246	1.1
	failure	3	253	290	52%	81.3	17.12%	251	1.2
East (quart)	intact		274	228	41%	49.4	10.40%	175	0
	failure	2	255	366	65%	76.1	16.02%	326	4.5
	failure	1	256	364	65%	76.7	16.15%	324	4.7
Northeast (head)	intact		227	176	31%	45.9	9.66%	140	0
	failure	1	227	272	49%	74.5	15.68%	231	0
	failure	6	227	265	47%	73.7	15.52%	223	0

2.5 Maximum horizontal displacement

The maximum horizontal displacement of the rig has been determined in accordance with the results of the mooring analyses. It also demonstrates the capability of the semi-submersible rig to withstand monsoons while supported by the mooring system when drilling the trial well (under the environmental conditions of the South China Sea). The maximum drifts of the semi-submersible rig are shown as follows:

1) When the semi-submersible encountered the monsoon once in 10 years, the maximum drift allowable would be 3.5% of its water depth;

2) When the semi-submersible encountered the monsoon once in 10 years, the maximum drift allowable would increase to 7% of its water depth under the condition that one mooring line had broken off.

2.6 Maximum loads of moorings

The maximum load on the moorings will occur when (in dynamics analysis) one of the mooring lines fails, i.e. when the rig encounters a monsoon or typhoon during drilling operation. Refer to Table 2.

2.7 Maximum loads of anchors

The maximum load of an anchor corresponds to the ability of the anchor to resist the tension created by the rig due to the weather. The illustrations are explained below:

1) The maximum allowable load of an anchor will be 176 tones when the mooring system is intact;

2) The maximum allowable load of an anchor will increase to 330 tones when the anchor's uplift angle is 4.8 degree with a failed mooring line.

3 Designs on moorings

3.1 Direction of semi submersible

According to the weather forecast, the northeast monsoon would occur during the drilling campaign at the well site in the period of March to May 2009. The heading of the semi-submersible rig would be designed 45 degree off the north, based on the principle that the bow of the rig should be against the direction of monsoon, as seen in Fig.1.

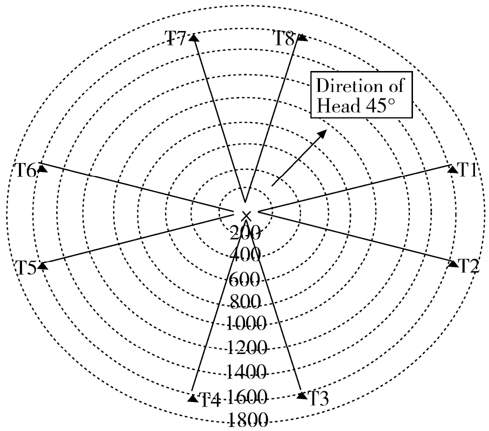

Fig.1 Arrange of Moorings by Semi of NH5

3.2 Deploying of moorings

There were two mooring layout models for selection; one was the taut leg model, and the other was the chains insert model, as shown in Fig.2.

Although both models satisfied the mooring criteria, the chains insert model was chosen for the trial well because of the availability of AHV vessels, economics, and the schedule. The results of analyses in accordance with the chains insert model are as shown in Table 4.

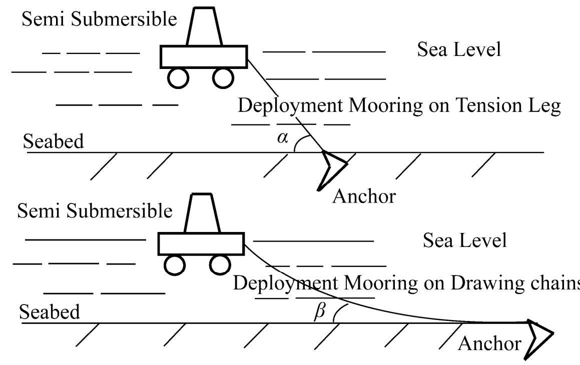

Fig.2 Models of moorings: Taut leg and chains insert

Table 4 Anchor lines tension/Distance /Bearing

Anchor No.	1	2	3	4	5	6	7	8
Water depth /m	483	493	500	495	468	458	454	459
Rig Tension /t	130	131	132	131	129	128	128	129
Chain Layout /m	475	480	483	480	470	467	466	466
Rig Chain Angle /(º)	45.1	45.5	45.8	45.6	44.6	44.3	44.2	44.3
Anchor Tension /t	45.	46	46	46	44	43	43	43
Chain on Seabed /m	408	403	399	401	416	424	427	422
Anchor Distance /m	1600	1600	1600	1600	1600	1600	1600	1600
Anchor Bearing /(º)	75	105	165	195	255	285	345	015

3.3 Composition of mooring

The diagram of mooring can be seen in Fig.3, showing the composition of the mooring line.

3.4 Procedure of mooring

Mooring procedures were drafted that covered design, mobilization, deployment, rig hook-up, and demobilization as follows:

1) The connection between the chains and the eight anchors had to be executed on the deck of AHV after the semi submersible rig had been delivered to the well site. Then installation of moorings could be completed on the deck of the semi-submersible;

2) The winches would haul in the chains, or retrieve the chains, until the tension of the chains reached 180 tonnes;

3) In the meantime, the semi-submersible rig adjusted its position accurately through retrieving or releasing the chain in each direction to achieve the tolerance required for drilling;

4) Finally, the chains would be adjusted until their tensions were uniform at around 130 tonnes;

5) During the trial well drilling, the tension of the chains would be kept between 130 to 180 tones and could possibly be adjusted in accordance with both the environment and engineering.

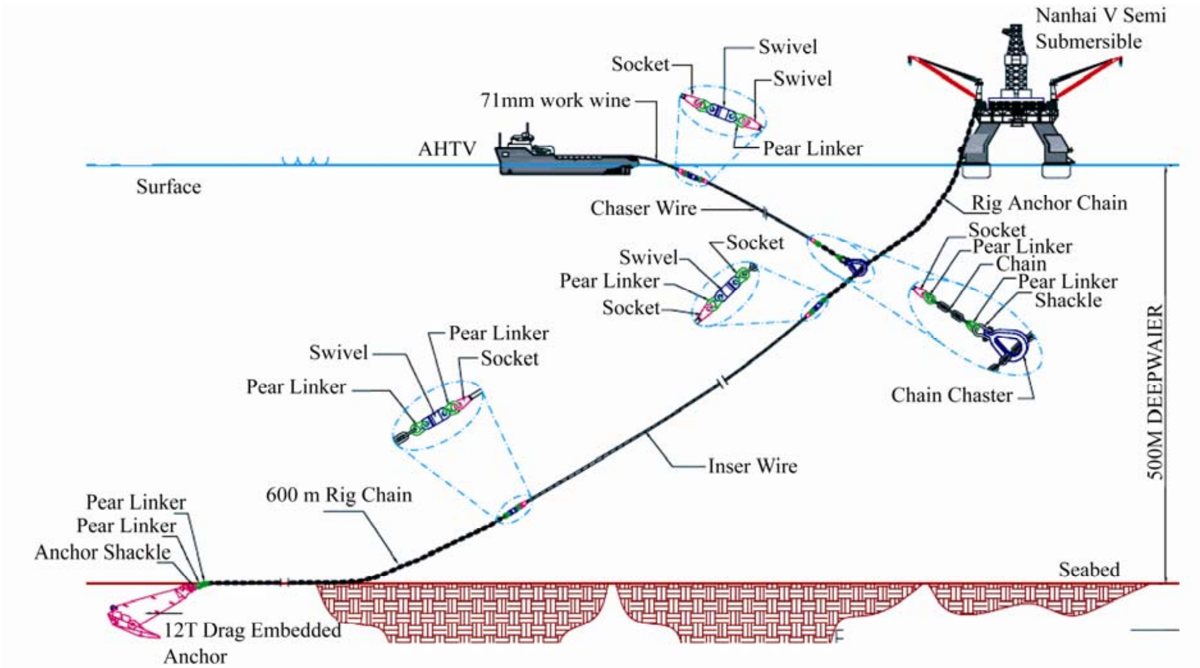

Fig.3 Composition of moorings of Nanhai V semi-submersible

4 Upgrading and operation

In terms of both analyses and designs of the moorings, the upgrading of the mooring system was conducted then the project of the trial well drilling in deepwater started in the South China Sea.

4.1 Upgrading of moorings

In general, it is necessary to use deepwater rigs to drill in deepwater areas. Most companies currently use the fifth or sixth generation semi-submersible rig to drill a well in deepwater. The Nanhai V is a second generation semi-submersible rig, and should be modified or upgraded before drilling a deepwater well.

The Nanhai V is a shallow water rig and its maximum operating water depth is 457 m. Its mooring equipment such as winches and chains are suitable for shallow water drilling only.

Much upgrading was carried out as seen below.

(1) The smaller anchors were replaced by bigger anchors in order to increase the anchoring force in the seabed; there were eight 12 ton anchors in the Nanhai V semi submersible rig originally, and they were replaced by new 15 ton anchors;

(2) The shorter moorings were lengthened to meet the requirements of drilling the trial well in deepwater areas; the Nanhai V originally had eight chains that were 1200m long, and needed to be increased to 1800m according to the design of the moorings; therefore a 600m steel wire was added in the chain to achieve the requirement.

4.2 Operation of trial well drilling

The mooring operation was conducted from March 28th, 2009 to May 10th, 2009 in the South China Sea. There were three AHVs that took part in the operation besides the Nanhai V semi-submersible rig. There were two stages of mooring operation for the trial well; one was the deployment stage, and the other was the retrieving stage.

1) In the deployment stage, the three AHVs were involved in setting the eight anchors around the Nanhai V semi-submersible rig from Match 28th, 2009 to April 10th, 2009, as seen in Fig.4.

2) In the retrieving stage, the three AHVs were involved in retrieving the eight anchors from the well site after the rig was demobilized from May 5th, 2009 to May 10th, 2009.

Fig.4 AHV of NH216's crews were anchoring in deepwater of South China Sea

5 Conclusions

The conclusions are summarized as follows:

1) A second generation semi-submersible rig may take on drilling in deepwater areas after modifying or upgrading relevant equipment, including the mooring system.

2) It is necessary to put forward a plan for upgrading the moorings after analysis and design in accordance with the design requirements.

3) In order to reduce the costs of upgrading the mooring and guarantee the safety of the operation, the analyses and mooring design should meet both requirements for monsoons once in 10 years and typhoons once a year.

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