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Analysis of Mooring System of Shuttle Tanker on Jack-up Platform

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***Abstract*—It is common to use the shuttle tanker to transport the oil in the marginal oilfield development. *However*, a reused shuttle tanker needs to reappraise its mooring safety. For certain water depth, after considering the various directions of wind and wave, a comprehensive analysis should be done on the mooring force of the shuttle tanker mooring system. We use different seed value waves and quasi dynamic analysis method to determine the shuttle tanker limit operating condition by changing the environmental parameter. The result shows that when the included angle of the horizontal projection of two chains and the direction of tanker length is 30 °, the mooring force of the mooring system is smaller than when it is 60 °. At the same time, in the case of 11.8 meters depth and 1.74 meters wave height, the tanker is unable to meet the requirements of safety operation. After step by step analysis, tanker mooring system can guarantee the safe operation when the wave height is no more than 0.6 meters, so as to accord with the safety operation condition.**

***Index Terms*—Shuttle tanker, mooring analysis, quasi dynamic method, limit condition.**

I. Introduction

With the rapid development of oil economy, the oil exploitation also shows diversify characteristics. Offshore oil field is becoming an important part of China's oil strategy [1], which includes a large number of marginal oilfield oil reserves. We often use the offshore pipeline transportation in marginal oilfield. However, when the oil reserve is low or it is too far from the shore, or simply its production period is short, the original oil transportation is uneconomical. In these cases we often use the shuttle tanker as replacement [2], [3]. Due to the different marginal oil field's location, we need to recalculate the operational safety of shuttle tanker every time.

Shuttle tanker uses the mooring line moor to the cylindrical foundation of the mooring platform, and uses mooring chain to moor the bow to the bottom of the sea. Under the influence of wind, wave and flow, the oil tanker will have different motion responses. So we can see the constraint of mooring system is very important. Insufficient mooring force will lead to chain breakage and accidents, and excessive oil tanker movement will lead to platform collision [4]. This paper analyzes the mooring force and the surge motion of a shuttle tanker ship operating in defferent sea areas with the certain water depth and different environmental conditions. The analysis uses the three dimensional potential flow theory and the quasi dynamic method, [5], [6], so as to determine its limit operating condition.

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II. Calculation Parameters

Fig. 1 shows the layout of the platform and tanker when shuttle tanker's output system is moored on the platform. The bow is anchored to the seabed by two anchor chains of No. 1 and No. 2, and the stern is moored to the platform by two nylon ropes of No. 3 and No. 4. The projection of anchor chains of No. 1 and No. 2 in the horizontal plane forms an angle α with the direction of the tanker's length, and we took α=30° as layout I and α=60° as layout II.

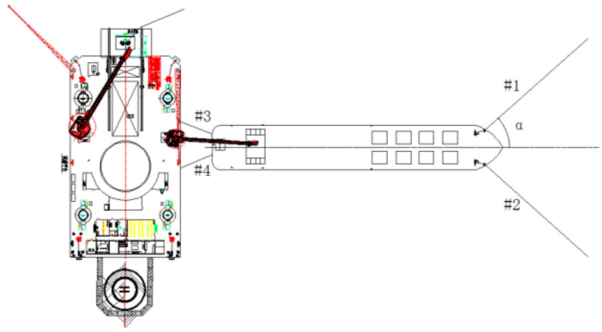

Fig. 1. Mooring system layout.

A. *Mooring System Parameter(According to Table I, Tabe II)*

TABLE I: Basic Parameters of Oil Tanker

Parameter	Value
Length（m）	88.02
Length between perpendiculars（m）	79.98
Molded breadth（m）	13.5
Moulded depth（m）	6
Draft（m）	5.2
Trim（°）	0
Designed displacement（t）	4495
Rolling radius Rxx(m)	4.6
Pitch radius Ryy(m)	20
Yawing radius Rzz(m)	20.8

TABLE II: Mooring System Parameter

Type	Diameter (mm)	Mass in water(Kg/m)	Axial stiffness（kN）	Breaking load (kN)
Anchor chain	38	32.4	1.27E+05	812
Moorign line	60	2.21	4.25E+02	657

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B. Operating Condition Parameter

The steady wind speed and flow velocity were adopted and JONSWAP spectrum (γ = 1.0) was chosen for the wave spectrum. 20 different wave seeds were selected and the quasi-dynamic method was used for statistical calculation [7].

According to BV NR493, the mooring analysis considered the wave in full circumference direction, i.e. 360°. The circumference direction is shown in Fig. 2.Considering the symmetry of the mooring system, the range of 0-180° was considered, which was divided into 9 directions with 22.5° for each interval. At the same time, different combinations of wind, wave and flow include:

(1) Wind, flow and wave are in the same direction;

(2) Wind is in the same direction as wave, while flow and wave form an angle of ±22.5°;

(3) Flow is in the same direction as wave, while wind and wave form an angle of ±22.5°;

(4) Wind and flow cross with wave on both sides of the wave, and form an angle of ±22.5° with wave respectively [8], [9].

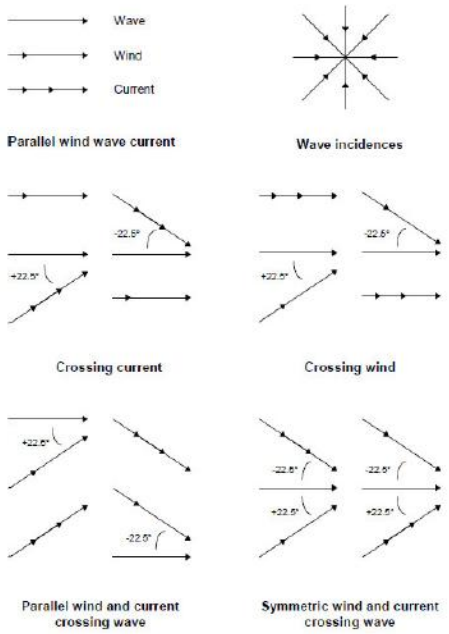

Fig. 2. Wind, flow and wave direction.

There are a total of 45 direction combinations. Wind-wave-flow combinations in full circumference direction can effectively determine the worst operating condition of the tanker in all circumstances, so as to avoid the occurrence of irreversible accidents. Environment parameter of the operating condition is expressed as Table III.

TABLE III: ENVIRONMENTAL PARAMETER

Condition	Wind speed (m/s)	Significant wave height Hs(m)	Wave period Tz(s)	Surface velocity (m/s)	Middle-level velocity (m/s)	Bottom velocity (m/s)
1	13.8	1.74	6.8	1.13	0.91	0.77
2	10	1	8	1.13	0.91	0.77
3	10	0.8	7	1	0.81	0.67
4	10	0.6	6.5	0.8	0.61	0.47

Operating condition 1 is a harsh environmental condition for the tanker, and the operating conditions 2 to 4 are successively adopted conditions according to calculation.

C. The Wind Force Coefficient and Flow Force Coefficient

1) The wind force coefficient

The wind force coefficients for mooring analysis is based on OCIMF code.The curve of the wind force coefficients on the full load condition see Fig. 3.

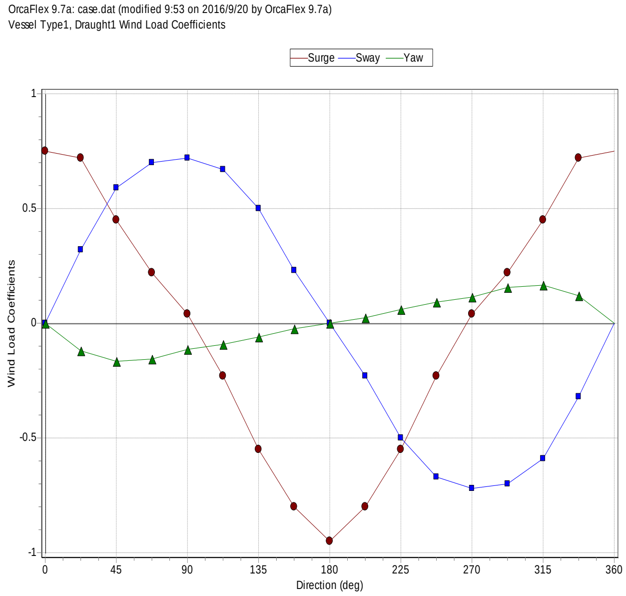

Fig. 3. The curve of the wind force coefficients on the full load condition.

2) The flow force coefficient

The flow force coefficient s for mooring analysis is based on OCIMF code. The curve of the flow force coefficients on the full load condition see Fig. 4.

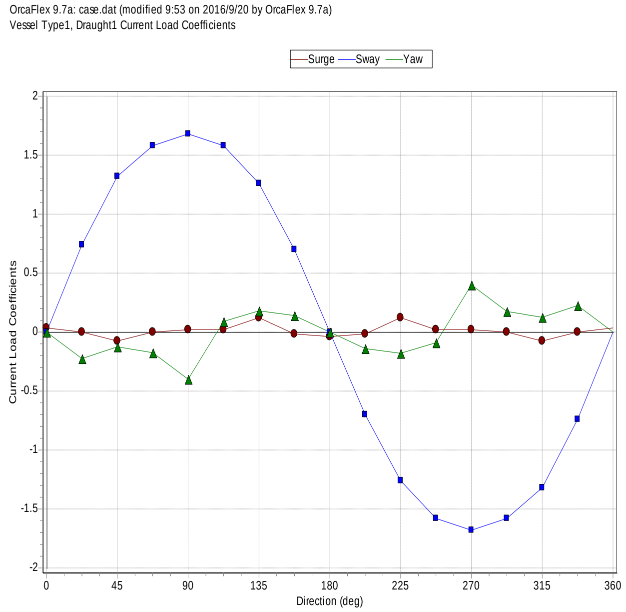

Fig. 4. The curve of the wind force coefficients on the full load condition.

III. Mooring Analysis

A. Mooring Method

ARIANE was used to analyze the mooring system, and the module can analyze the stress state of the mooring rope after the hull and mooring were coupled, and then compare the tension of mooring system with break tension to verify the safety of the mooring system. Based on the quasi-dynamic method, ARIANE obtained the low-frequency response of the hull with the numerical method in the time domain. After the numerical integration of all the time series, the low-frequency response is superimposed with wave motion and then the transient tension was obtained through the tension-deformation curve (anchor chain characteristics). The mooring system model is shown in Fig. 5 and Fig. 6.

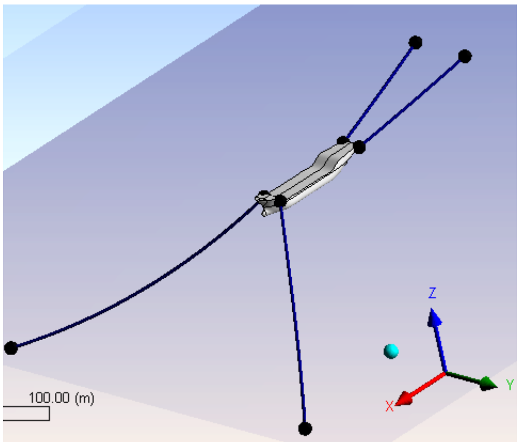

Fig. 5. Mooring system model.

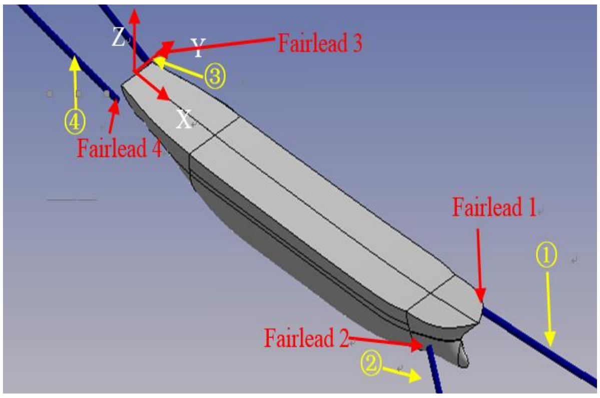

Fig. 6. Position of the mooring hole.

B. Calculation Results

1) Results analysis of operating condition 1

The results are shown in Table IV considering different direction combinations:

TABLE IV: Maximum Surge and Tension of Operating Condition 1

	Maximum surge		Maximum tention			
	+X	-X	Line1	Line2	Line3	Line4
Layout I	10.3	-1.3	1271	462	199	196
Layout II	15.8	-1.2	1321	437	255	234

Table IV shows that the maximum tension is greater than 1200kN, the break tension of anchor chain is 812kN, and according to BV NR493, the safety factor is 1.67, so the maximum allowable anchor chain tension is 486kN. Therefore, the anchor chain tension is much greater than the allowable value and cannot guarantee its safe operation.

Because of the space limitations, we only take the wind, wave and flow in the same direction as an example, and the result is shown in Table V: the maximum anchor tension appears in the beam sea direction, mainly due to the large tension of gull in beam sea and cross flow.

TABLE V: Maximum Surge and Tension When Wind, Wave and Flow Are in the Same Direction

No.	Condition			Max surge		Max tension			
	Wave	Wind	Flow	+X	-X	Line1	Line2	Line3	Line4
1	0	0	0	0.5	-1.3	187	187	51	51
2	22.5	22.5	22.5	0.9	-0.8	462	118	62	62
3	45	45	45	3.3	1.3	922	36	96	95
4	67.5	67.5	67.5	7.2	4.2	1252	11	143	141
5	90	90	90	9.2	5.6	1270	8	176	173
6	112.5	112.5	112.5	10.3	5.4	1008	8	199	196
7	135	135	135	7.9	3.3	722	41	187	186
8	157.5	157.5	157.5	4.8	1.7	549	346	160	159
9	180	180	180	1.6	-0.2	164	158	80	80

As can be seen from Table V, in the situation of beam sea and cross flow, the tension of anchor chain is greater than its breaking load; in this case, the tanker mooring system cannot guarantee its safe operation, but the mooring rope does not reach the maximum allowable tension, therefore, the analysis only considers the chain tension.

2) Results analysis of operating condition 2

TABLE VI: Maximum Surge and Tension of Operating Condition 2

	Max surge		Max tension			
	+X	-X	Line1	Line2	Line3	Line4
Layout I	7.2	-0.5	758	269	169	167
Layout II	13.4	-0.5	776	276	227	209

It can be seen from Table VI that the maximum tension is greater than 750kN, at this time, although the anchor chain does not break, it fails to meet the safety requirements of the specification, so the design chain tension is greater than the allowable value of the specification.

3) Results analysis of operating condition 3

It can be seen from the calculation results of the operating conditions 1 and 2 that, under the same environmental parameters, layout I is better than layout II, and so layout I is preferred. For operating condition 3, the maximum surge and maximum tension for layout I are shown in Table VII:

TABLE VII: Maximum Surge and Tension of Operating Condition 3

	Max surge		Max tension			
	+X	-X	Line1	Line2	Line3	Line4
Layout I	4.9	-0.4	536	226	143	141

It can be seen from Table VII, the maximum tension is 536kN, greater than the allowable stress of 486kN, so the environmental parameters still cannot meet the safety requirements.

4) Results analysis of operating condition 4

TABLE VII: MAXIMUM SURGE AND TENSION OF OPERATING CONDITION 4

	Max surge		Max tension			
	+X	-X	Line1	Line2	Line3	Line4
Layout I	2.4	-0.3	343	167	103	102

It can be seen from Table VII, the maximum tension is 343kN, smaller than the allowable stress of 486kN, so the environmental parameters meet the safety requirements.

C. Results Analysis

Through the calculation of the four operating conditions, it can be seen that only layout I meets the safety requirements in the environmental parameters of operating condition 4, while other conditions cannot guarantee safe operation.

Through the tension analysis of anchor chain and the mooring rope, the characteristics of a single anchor chain are only related to the properties of anchor chain itself (axial stiffness, weight), water depth, horizontal span, and pre-tension. The current horizontal span of anchor chain is 200m, and the water depth is 11.8m. The catenary shape of anchor chain is showed Assuming pre-tension is 81.2kN, the catenary is shown in Fig. 7.

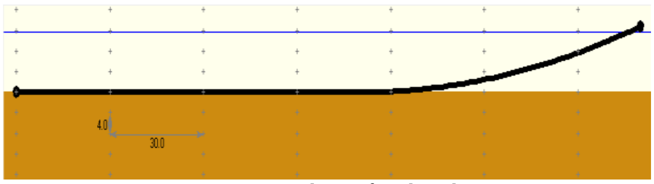

Fig. 7. Catenary shape of anchor chain.

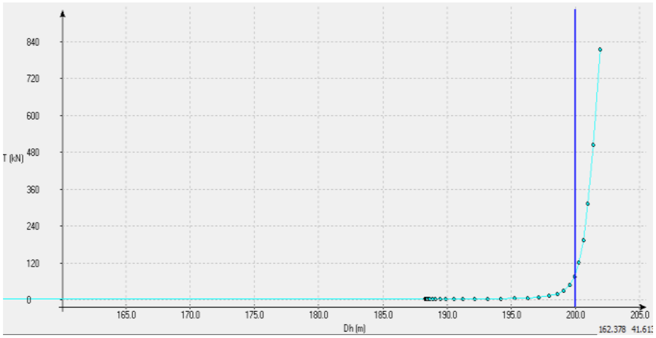

Fig. 8. Axial force and horizontal span of single anchor chain.

The relationship between the axial force and the horizontal span is shown in Fig. 5. Because of the shallow water depth, the forepart of anchor chain, which is about 200m away, has almost no contribution to the rigidity of the mooring system; the rigidity of rear section increases sharply; when the horizontal span increases from 200m to 202m, the chain tension increases from 80kN to break force of 812kN, resulting in the excessive rigidity in the entire mooring system, and the anchor chain tension increases dramatically where it is close to the ship-side. The rigidity of the mooring rope is much smaller than that of the anchor chain, when it reaches the break force, its affordable deformation is much greater than that of anchor chain.

IV. CONCLUSION

1) From the comparison of two kinds of mooring layout, it can be seen that layout I is better than layout II, and layout I can withstand more environmental load.
2) The tanker and the mooring system can operate safely under the environmental conditions with the wave of no more than 0.6m high.
3) The mooring system can be safely used under restricted operating conditions, which has opened up a new model of oil tanker system in the output of crude oil on platform, but it is affected by environment and should strictly limit the operation window during the actual use.

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