

Analysis and simulation of a single buoy mooring system based on sea environment

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ABSTRACT:

Single Point Mooring (SPM) is of great use to offshore floating structures which are currently in use in Vietnam's coastal waters. However, this country is facing the lack of the related guidelines and standards for analysis, simulation and design of SPM system. This fact is the rationale for this paper which is aimed to propose a procedure for computation of the effects of sea environment on a SPM system. Specifically, the procedure

enables the identification of maximum load exerting on the mooring buoy. Then, such identification together with the water depth parameter enables the determination of the optimal length and diameter of the desired chain. Finally, this paper presents a primary simulation of the mooring chain system according to various water depth conditions.

Keywords: *Single point mooring, mooring chain, SPM.*

1. INTRODUCTION

For the offshore oil and gas industry nowadays, the use of floating storage to store, process and extract crude oil is an effective solution to offshore deep-water oil fields especially ones located on marginal zones in which the construction of the above floating storage systems are more cost-effective than the pipelines. The floating production, storage and offloading (FPSO) moored to SPM system is being used more widely in Viet Nam. The safety and stability of SPM is extremely important and necessary to improve the productivity when FPSO is working. However, most of the previous researches on this issue focus on the stability of mooring lines with sinkers and without the sinkers[4], as well as on the usage of ANSYS AQWA program to simulate the motion of mooring lines[3]. Therefore, the

understanding of the effect of parameters on the design and simulation of mooring lines is limited, which causes difficulties for the design, inspection, and maintenance of mooring lines. Based on the foregoing reality, the authors present the theories and algorithms in the design and simulation of mooring lines. Simultaneously, according to the studied algorithms [1], we build a program by Matlab [6] to shorten the computation's time. Then, the actual hydrological parameters and FPSO data [2], [5] are used to run the program and the outputs will be examined. Finally, from the results, we will evaluate and draw conclusions about the parameters affecting the design and simulation of mooring lines.

2. DESCRIPTION OF PROBLEM

The practical construction in this report is FPSO Ruby Princess, which operates in Ruby water located in block 1 and 2, offshore Vietnam, approximately 155 km Northeast of Vung Tau. FPSO's specification is presented in Table 1. The vessel operates at the depth of 50 m where the environmental variation is not extreme. It uses the SPM with the mooring chains being distributed in three different directions with equal angles. Each direction has three chains to ensure that when the vessel is working, there will be at least two or more mooring chains bearing the load. Additionally, the influences of the current, wind and tide are also taken into account, behavior of mooring under environmental loading can be seen in Figure 1. From all the mentioned factors, the authors have computed and converted them to the horizontal load on the buoy by the algorithm "Equilibrium Position" from which the maximum horizontal load on the buoy will be determined. Then, we will use the horizontal load known from the procedure to study the parameters impacting on the behavior of Buoy – Chain – Anchor such as working depth, length and diameter of chain.

The properest parameters of working depth, length and diameter of chain for Princess will be determined by assuming the horizontal load H the same at every point in this report. The actual chain length is also assumed to be 600 m. The diameter of chain is 120 mm.

Table 1. FPSO Ruby Princess' specification

LOA	202 m
LBP	260.0 m
BMLD	43.30 m
DMLD	22.45 m
DWT	140.900 T
LOADED DISPLACEMENT	161.200 T
LOAD DRAFT	17.07 m
BALLAST DISPLACEMENT	73.000 T
BALLAST DRAFT	9.20 m

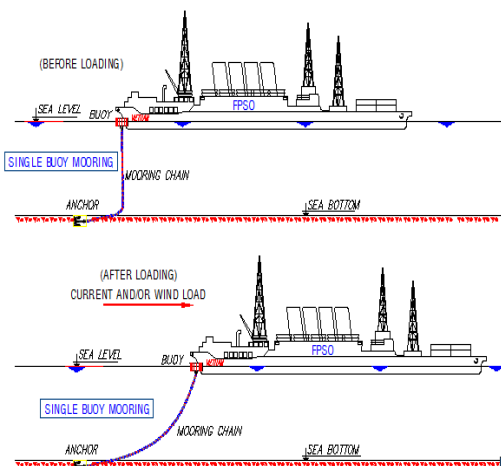


Figure 1. Behavior of mooring under environmental loading

3. DETERMINATION OF MAXIMUM LOAD ON SPM SYSTEM

3.1. Modelization of impacts on FPSO

This section describes methods for determination of static wind and current load on single moored vessels. The horizontal load, longitudinal force, and yaw moment are evaluated. Figure 2 defines the coordinate system and nomenclature for describing these loads. The angle between the wind and the current is θ_{wc} . The wind angle, θ_w , and current angle, θ_c are defined as positive in clockwise direction. The discussion of the various physical phenomena involve in this procedure is provided in following section.

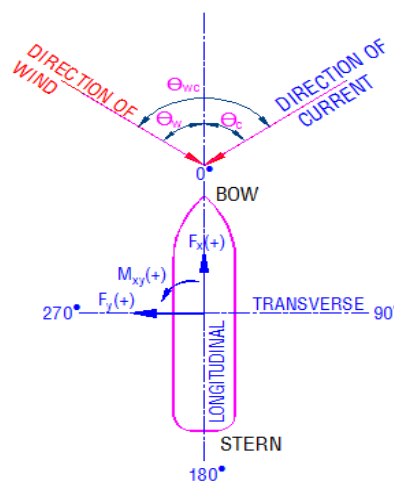


Figure 2. Coordinate system and nomenclature for wind and current load Procedure

The procedure for determination of the maximum horizontal load¹

- Step 1 of the procedure for determination of the maximum horizontal loads to input the hydrological and ship parameters.

- Step 2 in the process is to analyze the effective loads including the sum of the horizontal loads, the sum of the longitudinal loads, and the sum of the yaw moments on mooring elements as indicated in the following:

$$\begin{aligned} F_{xT} &= F_{xw} + F_{xc} \\ F_{yT} &= F_{yw} + F_{yc} \\ M_{xyT} &= M_{xyw} + M_{xyc} \end{aligned} \quad \square \quad (1)$$

- Step 3 of the procedure is to determine the sum of moment:

$$\sum M = M_{xyw} + M_{xyc} - F_{yT}ARM \quad \square(2)$$

If the sum of moments is not equal to zero, then start the loop from scratch with the different hydrological parameters until the total moment is zero.

- Step 4 consists of calculating the maximum horizontal load acting on buoy.

$$H^2 = F_{xT}^2 + F_{yT}^2 \quad (3)$$

General procedure for determination equilibrium point of zero moment and maximum horizontal load is given in Figure 3 below

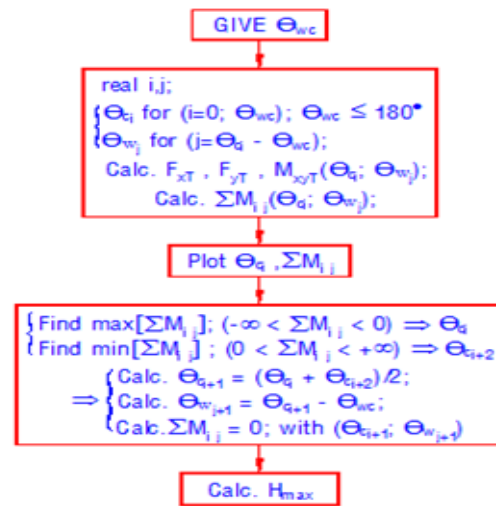
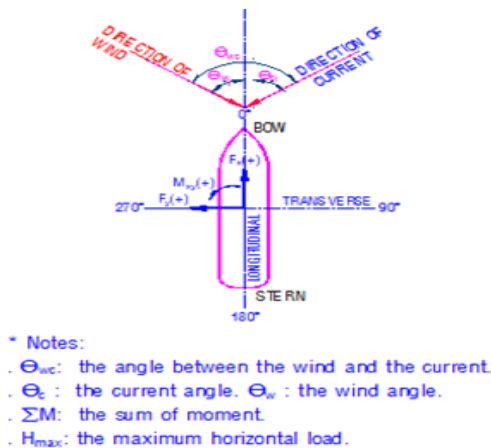


Figure 3. Procedure for determining equilibrium point of zero moment and maximum horizontal load

4. ANALYSIS AND SIMULATION OF MOORING CHAIN SYSTEM

3.2. Definition and scope of computation

The plot describes relationship between the horizontal load, water depth and catenary parameters is represented in Figure 4.

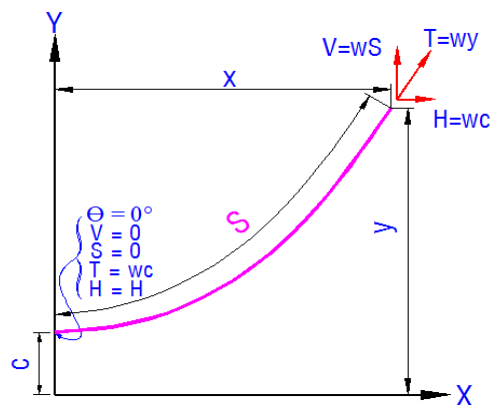


Figure 4. Definition sketch for the use of catenary analysis

At any point (x, y) the following hold:

$$\begin{aligned} H &= wc = T \cos \theta \\ T &= wy \end{aligned} \quad (4)$$

Where: V= Vertical force at point (x,y)

W= Submerged unit weight of chain.

S= Length of curve (chain length) from point (0, c) to point (x, y).

T= Line tension at point (x,y)

θ = Angle of mooring line with horizontal

H= Horizontal load at point (x,y)

C= Distance from origin to y – intercept = H/w

• Formulas

The shape of the catenary is governed by the following:

$$\begin{aligned} y^2 &= s^2 + c^2 \\ y &= c \cosh(x/c) \\ s &= c \sinh(x/c) \quad (*) \end{aligned} \quad (5)$$

Equation (*) may be more conveniently expressed as:

$$x = c \ln \left[\frac{s}{c} + \sqrt{\left(\frac{s}{c}\right)^2 + 1} \right] \quad (6)$$

Note that, in the above equations, the horizontal load on the chain is the same at every point and that all measurement of x, y, and S are referenced to the catenary origin.

3.3. Procedure

The procedure for computing of catenary¹

- Step 1 of the procedure is to input parameters θ_a , w_s , w_d , and H

- Step 2 is for the distance from origin to y to be determined – intercept $c = H/w_s$

- Step 3 in the row is to compute the height from origin to buoy, given as:

$$y_b = c + wd$$

- Step 4 in computing the catenary is to determine the chain length from anchor to buoy, expressed by:

$$S_{ab} = \sqrt{y_b^2 - c^2} \quad (7)$$

If $S_{ab} > S_{actual}$ then increase the chain length until $S_{ab} < S_{actual}$

- Step 5, the horizontal distance from the anchor to the buoy is defined as:

$$x_{ab} = c \cdot \ln \left[\frac{S_{ab}}{c} + \sqrt{\left(\frac{S_{ab}}{c}\right)^2 + 1} \right] \quad (8)$$

- Step 6, the tension in the mooring line at the buoy is represented: $T_b = ws \cdot y_b$

- Step 7 in the process is to compare T_b with T_{break} and reach the conclusion about the ship condition as follows.

If $T_b < T_{break}$ Ship is safe.

If $T_b > T_{break}$ Therefore, we need to calculate the working depth again to assure the ship's anchor. Numerical results NUMERICAL RESULTS

3.4. The maximum horizontal load

3.4.1. Input

FPSO's specification is presented in Table 1 and the statistics on actual hydrological parameters of direction and velocity taken at the site are given in Table 2.

Table 2. Input parameters of the hydrology

Direction	θ_{wc} (degrees)	V_w (m/s)	V_c (m/s)	α^o (of V_c)
N	120	36.20	0.87	240
NE	163	45.00	1.20	242
E	83	29.10	0.92	277
SE	94	19.20	1.54	41
S	112	21.40	1.76	70
SW	146	33.40	1.65	79
W	172	32.70	1.60	78
NW	180	31.80	1.05	135

All θ angles are defined between 0 and 180 degrees. Use V_w and V_c of 45 m/s and 1.76 m/s respectively for all θ_{wc} to determine the point of equilibrium (sum of moment is equal to zero) and corresponding horizontal loads.

3.4.2. Plots of sum of moment

First, the parameters are inserted to the algorithm. For each angle θ_{wc} , a series of total moment values and an equilibrium position of zero moment corresponding to each pair of angle θ_c and θ_w in the range of θ_{wc} will be

determined, then the results are presented in the following plots.

3.4.3. Results of maximum horizontal load

From the computation and the plot of sum of moments, $\Sigma M = 0$, versus θ_c and θ_w in the previous section, the corresponding values of maximum

horizontal load H are determined. The results are presented in Table 3 as follows.

The maximum value of the horizontal load H is set at 1,144.897 T, which is the representative horizontal load for all the wind directions and currents based on the design probability in order to compute the mooring lines in water.

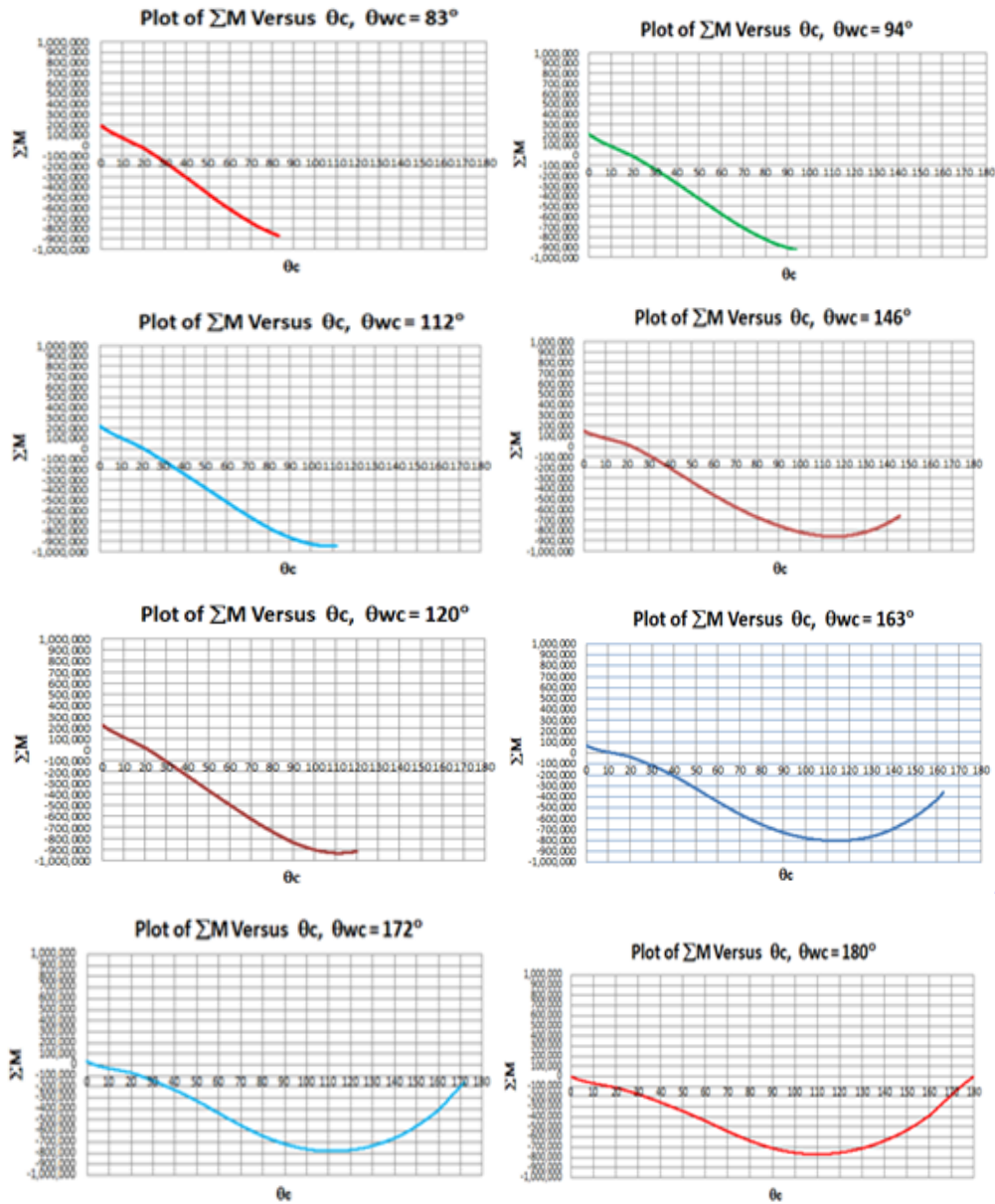


Figure 5. Plots of ΣM versus θ_c and θ_w

Table 3. Results of horizontal loads

Direction	θ_{wc} (degrees)	θ_c relative to vessel bow (degrees)	H Horizontal load (Tons)
N	120	21.6	1,089.500
NE	163	12.6	786.264
E	83	17.5	715.803
SE	94	19.0	825.543
S	112	20.8	1,007.831
SW	146	22.1	1,144.897
W	172	3.6	188.583
NW	180	0.0	9.715

3.5. The results of the relationship between water depth and the parameters of mooring lines

3.5.1. Supporting computational tools

Authors have used Matlab’s program⁵ to simulate procedure for determining the parameters which include the length of the chain from anchor to buoy (S_{ab}), the horizontal distance from the anchor to the buoy (x_{ab}), the tension in the mooring line at the buoy (T_b), and the vertical load at the anchor (V_a). From the result, we will examine the relationship between the water depth, chain length and chain section in order to make the most appropriate choices for ship operations.

3.5.2. Input

Input parameters consisting of Chain length, Horizontal load ($H/3$), Water depth (w_d), and Submerged unit weight of chain (w_s).

Table 4. Input parameters

Chain length (m)	H (T)	w_s (T/m)	w_d (m)
600	381.0	0.25	50

3.5.3. Results

* Results of relationship between water depth and different parameters of catenary

The water depth is varied from 50 m to 150 m to determine the largest water depth and afterwards the chain length will be estimated while ship is working at a corresponding depth water. The calculation results of the relationship between water depth and traction, chain length are shown in table 5. These values increase linearly together. The relation plots are provided in Figure 6 and 7.

Table 5. Results when the water depth changes

w_d (m)	50	70	90	110	130	150
S_{ab} (m)	393.740	467.369	530.723	589.638	643.021	692.907
x_{ab} (m)	389.484	460.347	520.569	575.867	625.358	671.049
T_b (T)	393.834	398.832	403.758	408.834	413.833	418.835

* Relationship between diameter and different parameters of catenary⁴: At the water depth of 50 m and 70 m, when the diameter of chain increases from 122 mm to 132 mm, the relation between the chain
- At water depth of 50 m :

length, horizontal distance and traction is identified. The calculation results at the depth of 50 m and 70 m are indicated in Table 6 and 7, respectively.

Table 6. Results when the water depth is 50 m

D (mm)	122	124	127	130	132
S_{ab} (m)	378.784	372.734	364.040	355.862	350.694
x_{ab} (m)	374.376	368.235	359.449	351.150	345.922

T _b (T)	394.859	395.308	395.997	396.691	397.159
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- At water depth of 70 m:

Table 7. Results when the water depth changes to 70 m.

D (mm)	122	124	127	130	132
S _{ab} (m)	449.7376	442.624	432.3792	422.712	416.6016
x _{ab} (m)	442.4416	435.2064	424.7792	414.96	408.728
T _b (T)	400.2658	400.9008	401.8624	402.8376	403.4908

From the results in Table 6 and 7, it can be seen that when the diameter of chain ascends, the traction is in direct proportion, whereas the chain length and horizontal distance descend. The relation plots are shown in Figure 8,9, and 10, respectively.

3.5.4. Plots

- Relationship between water depth and different parameters of catenary and relationship between diameter and different parameters of catenary are presented in the following figures:

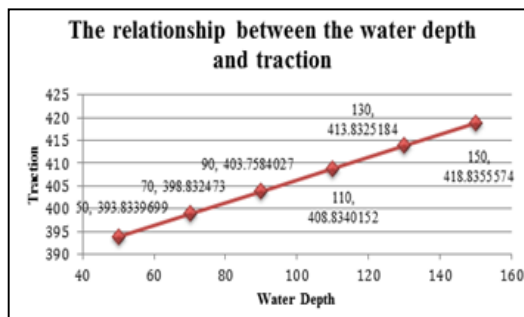


Figure 6. The relationship between the water depth and traction

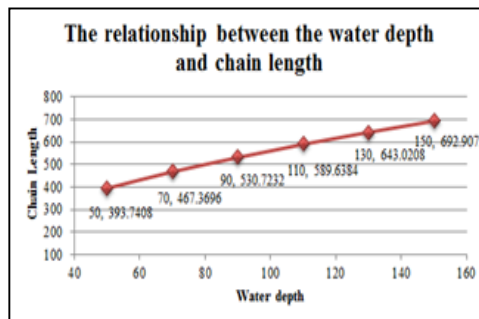


Figure 7. The relationship between the water depth and chain length

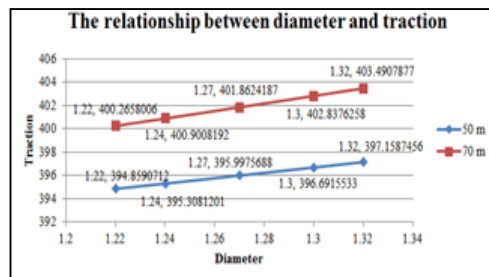


Figure 8. The relationship between diameter and traction

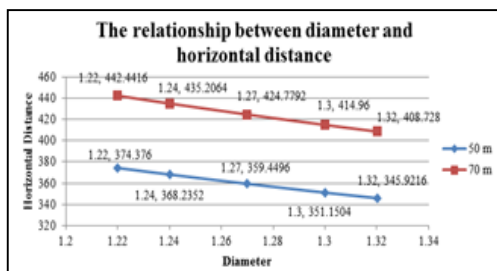


Figure. 9. The relationship between diameter and horizontal distance

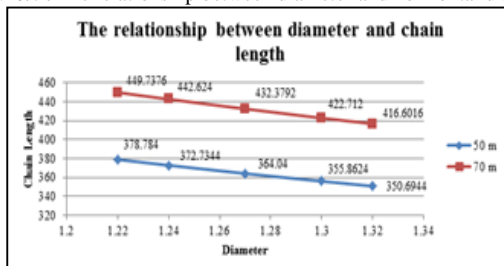


Figure. 10. The relationship between diameter and chain length

- Relationship between different horizontal load levels and horizontal distance is presented in the following Figure 11:

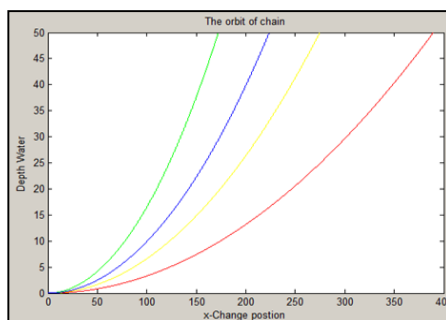


Figure. 11. Behavior of catenary following the horizontal distance when it is affected by different horizontal loads ($w_d = 50$ m, $d = 120$ mm)

5. CONCLUSIONS

The parameters given by the authors have a close relation with each other. When w_d changes, S_{ab} is the most affected parameter. It can be seen that w_d increases to 130 m, the initial assumed chain length is not sufficient to anchor the vessel. The length needs to increase to 700 m or more in this case. Meanwhile, T_b at the depth of 150 m is still working fine ($T_b < T_{break}$ of 1220.267T); thus, the initial diameter of catenary satisfies the working conditions. When w_d is fixed and w_s varies, it is clearly that the rise in w_s leads to the fall in S_{ab} and x_{ab} in comparison with the surge of T_b . The more increase in depth, the more different the parameters are from the others.

From the above relationship, it is noticeable that if the depth parameter changes, most of the other parameters will be affected, especially S_{ab} , which does not satisfy the initial assumption. Therefore, we should consider S_{ab} in working environment to assure work requirements and wasting. For FPSO Ruby Princess working at a depth of 50 m, the required length of catenary is about 400 – 500 m.

In this paper, the authors only analyze in term of a specific procedure, so as if, the actual chain length is less than the computed. Therefore, we should study more and more to increase or decrease the length to the optimal and the most economical one. Besides, according to the general procedure¹¹, we can perform

the loop to choose the vertical load at the anchor. Then the tension at buoy is computed again in order to strengthen the test for catenary. This issue will be presented specifically in the later article.

These parameters are interdependent. Hence, as we contemplate the change in any parameter, should consider the relationship between them in order that the system Buoy – Chain – Anchor works stable and safe.

Phân tích và mô phỏng hệ thống phao neo đơn

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TÓM TẮT:

Phao neo đơn (SPM) được sử dụng phổ biến cho các kết cấu nổi FPSO (The floating production, storage and offloading) ở vùng biển thềm lục địa Việt Nam. Tuy nhiên ở nước ta vẫn thiếu các chỉ dẫn kỹ thuật và tiêu chuẩn liên quan để phân tích, mô phỏng và thiết kế hệ thống SPM. Đề tài này nhằm mục đích đề xuất quy trình xác định ảnh hưởng của tải trọng môi trường lên hệ thống SPM.

Từ khóa: Phao neo đơn, xích neo, SPM.

Cụ thể là với quy trình này có thể xác định được chính xác vị trí cân bằng tổng mô-men của FPSO và lực ngang lớn nhất tác dụng lên SPM. Từ đó với thông số độ sâu nước xác định có thể tối ưu hóa chiều dài và đường kính xích mong muốn. Đề tài trình bày những mô phỏng căn bản của hệ thống xích khi thay đổi chiều sâu nước.

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