PAPER • OPEN ACCESS

Research on dynamic responses of mooring line system of semi-submersible platforms in Vietnam sea conditions using random model

View the article online for updates and enhancements.

Research on dynamic responses of mooring line system of semi-submersible platforms in Vietnam sea conditions using random model

H H Pham[1, *] , **T Mai[1]** and **Y Liu[2]**

[1] Hanoi University of Civil Engineering, Vietnam
[2] Norwegian University of Science and Technology, Norway

[*] Correspondence: hauph@huce.edu.vn

Abstract. Recently, due to the nearshore oil fields in Vietnam were nearly exhausted, oil and gas extraction proceeds to deeper water areas using the mooring floating offshore structures. Therefore, the durability of the mooring system in deep water should be studied through determining the dynamic tension of the mooring line system using random wave models. However, full stochastic dynamics analysis for mooring line system takes up a lot of time and requires large computing resources. This paper is going to study the hydrodynamic interaction of random waves onto a semi-submersible platform, thereby analysing the dynamic responses in time domain of the mooring system using the "time window" method to optimize computational time and computing resources. This method performs the dynamic simulations around the maximum quasi-dynamic tension values to determine the dynamic tension and the dynamic amplification factor (DAF) of a maximum load-bearing mooring line, thereby evaluating the dynamic responses for the whole mooring system. The method is applied to calculate for a semi-submersible platform in Dai Hung field in Vietnam Sea.

1. Introduction

The exploitation of oil and gas in Vietnam's offshore waters and deep continental shelf waters is in the development stage and has great potential due to the secondary exploitation of nearshore fields. The use of floating offshore structures including semi-submersible platforms to serve oil and gas exploitation in deep water areas is an inevitable need. The reason is that these structures have advantages such as flexibility in use, exploitation from shallow water to deep water, can be moved from one field to another and reusable.

A Semi-Submersible platform (also known as Semi- Floating Production Units – FPU or Semi-Floating Production System - FPS) consists of a rectangular deck structure supported by 4 to 8 surface-piercing vertical columns standing on submerged horizontal floaters. The vessels are moored by means of 8 to 12 catenary mooring lines consisting of chains or combinations of chain and wire (see Figure 1).

The study of the dynamic responses of mooring line system of semi-submersible platforms is one of the important problems for determining the durability safety of this structure. From the results of hydrodynamic force calculations on FPU, the dynamic response analysis of FPU's mooring system will be performed using quasi-dynamic and random dynamic simulations of mooring line tension according to the time domain analysis method. In this paper, the authors propose a sequence of practical computational steps for the problem of dynamic response analysis of mooring line systems to

preliminarily quasi- dynamic calculate for the entire mooring system and for all sea states. From there, the most dangerous mooring line and sea state are selected to conduct detailed dynamic response through the dynamic amplification factor (DAF) of the mooring line. For each quasi-dynamic tension simulation during 3 h, the method of selecting a "time window" around the maximum quasi-dynamic tension value for line dynamic calculation is carried out, in order to optimize the time and resources for dynamic calculation. To calculate the design dynamic tension of the mooring line, in a simulation it is only necessary to take the maximum peak value. Therefore, selecting the "time window" around the max peak value of the quasi-dynamic simulation for dynamic calculation can ensure the accuracy of the results while optimizing the calculation time. The study has been applied to the mooring system of Dai Hung 01 semi-submersible platform (FPU DH01) at Dai Hung field, using the software of Bureau Veritas (HydroSTAR, ARIANE-3D and MCS-Cable) for dynamic analysis of mooring lines subjected to random waves.
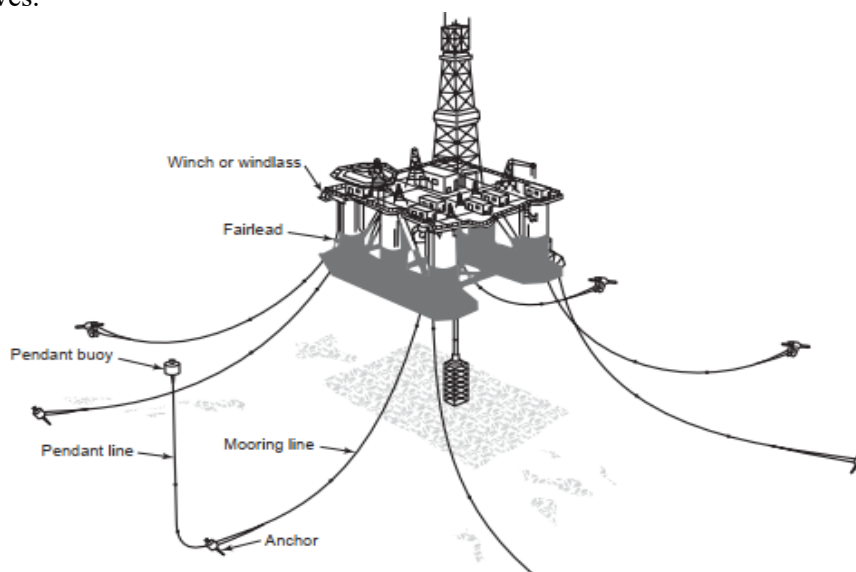
Figure 1. Typical semi-submersible platform [1]

2. Research steps

To implement the above research objectives, a sequence of steps as follows was performed:
- Research on the methodology of calculating the dynamic response of the mooring line of a FPU according to a random model: from the response amplitude operators (RAOs) transmission functions of the FPU's motions the hydrodynamic forces according to [7,8], using the analysis method in the time domain to solve the random dynamic problem in 2 steps: quasi-dynamic and dynamics analysis of mooring lines.
- Collection of the environmental data, the design parameters of FPU DH01 and its mooring system.
- Using HydroStar software to calculate the RAO of motions and hydrodynamic forces under the random waves acting on FPS-DH01 to calculate the mooring line system.
- The quasi-dynamic tension in mooring system is calculated according to the simulations during a 3-hour storm. In order to minimize time and resources for line dynamic calculation, select the "time window" around the maximum quasi-dynamic tension of the mooring line with the lowest safety factor in the most dangerous sea state to calculate dynamic simulation.
- Calculate the line dynamic tension in the above step, thereby determining the dynamic amplification factor (DAF) of the line tension.
- Evaluate the dynamic influence of the FPU's mooring system affected by random waves through the DAF.
- Determine the safety factor and the strength of the mooring lines from the design dynamic tension.

3. Methodology for calculating the dynamic response of the FPU's mooring system

The tension of the mooring line can be calculated under the action of extreme environmental forces according to two methods: Quasi-dynamic and dynamic analysis of the mooring lines.

In the quasi-dynamic analysis method, the problem can be solved in the frequency domain (also known as the spectral method) or in the time domain. However, the disadvantage of the spectral method is that this method can only solve the linear problem (quasi-dynamic analysis) and not the nonlinear problem (line dynamics analysis). Therefore, in the case of mooring line analysis according to both quasi-dynamic and dynamic methods, simulations of line tension should be analyzed in the time domain [3,9,10,11].

3.1. Quasi-dynamic analysis of the mooring lines in the time domain

According to [3], when analyzing the quasi-dynamic responses of the mooring lines in the time domain, the tension of the lines is determined from the quasi-static response of the lines due to the motions of FPU at fairlead (connection point between the line and FPU). The FPU is only affected by environmental forces acting on the floating structure, ignoring the environmental force acting on the mooring line.

Scope of application: Quasi-dynamic analysis method is suitable for calculating structures operating at shallow and medium water depths.

3.1.1. Quasi-dynamic simulation steps in the time domain.
First, when there is no external force acting on the FPU, the FPU establishes the initial equilibrium position by the pre-tension in the mooring line. Then external forces are applied to the FPU, which are sub-divided as follows (see Figure 2):
 – Steady component: the mean forces due to mean wind and current speeds and mean wave drift;
 – Low frequency component: the slowly varying low frequency force (LF);
 – High frequency component: the high frequency force oscillating with wave frequency (WF).
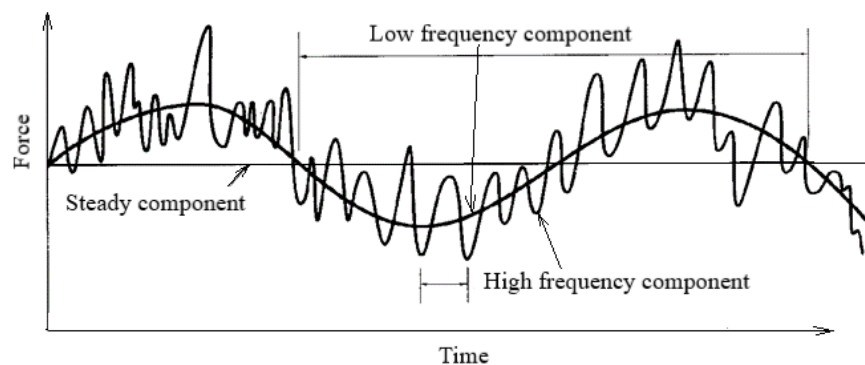
Figure 2. Components of external forces acting on semi-submersible platform (FPU) [3].

Under the action of external forces, the FPU is moved and create the mooring system response. The obtained signal of the tension is composed of three components:
- Mean response: static equilibrium by steady forces. The first component is due to the mean effect of wind, wave and current;
- Low frequency response: application of low-frequency forces at equilibrium position. The second component is due to the slow variation of the tension under the wave slow drift effect (second order wave drift load) and/or the wind gusts effect.
- Wave frequency response: addition of wave frequency responses on low-frequency response. The third signal is a variation of the tension at the wave frequency around the low frequency tension. This component is due to the wave-induced motion of the FPU (first-order wave motion).

(1) *STATIC ANALYSIS:* During the static analysis phase, under the action of the mean force of wind, current, and mean drift force of waves, the FPU will be changed to a new equilibrium position. The external forces are balanced by the tensions at fairlead of the mooring lines. Around this new

equilibrium position, the FPU performs the low-frequency and wave-frequency motions. After static analysis, the quasi-dynamic simulations in the time domain are performed.

(2) *LOW FREQUENCY:* At each time step t, the low-frequency displacement component is achieved by solving the following differential equation of motion [6,7,8,10]:

$$\sum_{j=1}^{6}\left\{\left[\boldsymbol{M}_{ij}+\boldsymbol{M}_{a_{ij}}\left(\omega\right)\right]\ddot{\boldsymbol{X}}_{j}+\boldsymbol{B}_{ij}\left(\omega\right)\dot{\boldsymbol{X}}_{j}+\boldsymbol{K}_{ij}\boldsymbol{X}_{j}\right\}=\boldsymbol{F}(t) \tag{1}$$

where $\boldsymbol{X}_{j}$, $\dot{\boldsymbol{X}}_{j}$, $\ddot{\boldsymbol{X}}_{j}$ are the motion, velocity, and acceleration vectors at the center of gravity G of the FPU, respectively; $\boldsymbol{M}_{ij}$ and $\boldsymbol{M}_{a_{ij}}$ are the mass matrix of floating structure and additional mass matrix, respectively; $\boldsymbol{K}_{ij}$ is the stiffness matrix of FPU; $\boldsymbol{B}_{ij}$ is the damping matrix; and $\boldsymbol{F}(t)$ is a vector with 3 components of the horizontal load applied at the center of the FPU at the time step t.

(3) *WAVE FREQUENCY:* At each time step after the numerical integration of the low frequency response, the 6 wave frequency motions of the FPU at centre of gravity are added to its low frequency position. The wave frequency motions derived from the Response Amplitude Operators (RAO) of the FPU.

3.1.2. Calculate the design quasi-dynamic tension of the mooring line. In order to avoid an undue numerical transitory response at the beginning of the simulation, it is recommended that the FPU not be suddenly submitted to the time varying components of environmental loads. The beginning of the response signal is therefore to be truncated. The time to start recording the simulation (t_1) is when the system is in equilibrium. According to the design experience of floating structures with catenary mooring lines (of FPU or FPSO/FSO), t_1 is about from 2000s to 5000s, depending on the rigid of mooring system (conventional multi buoy mooring, yoke, soft-yoke, …). In the ARIANE software, there is a function to find the initial equilibrium position in the static analysis. In this study for the application of FPU DH01, we use t_1 is 2000s.

In order to calculate the design quasi-dynamic tension of the mooring line in the time domain, it is necessary to perform n quasi-dynamic simulations ($n \geq 5$) for each sea state of a short storm of 3 h (10,800 s). The simulations of the mooring line tension are calculated for each random wave seeding number (seed). Each simulation gives a maximum tension value, thereby calculating the mean and standard deviation of those n maximum tensions to calculate the design tension of the line in intact conditions, according to equations (2,3,4) [2,10]:

$$T_{D}=T_{M}+aT_{S} \tag{2}$$

$$T_{M}=\frac{1}{n}\sum_{k=1}^{n}T_{k} \tag{3}$$

$$T_{S}=\sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left(T_{k}-T_{M}\right)^{2}} \tag{4}$$

Where T_D is the design tension of the line; n is the number of simulation; T_k is the maximum tension at fairlead achieved in the k-th simulation; T_M, T_S are the average value and the standard deviation of T_k obtained by n simulations, respectively; a is the coefficient depending on n and the analysis method. If the quasi-dynamic method is applied, then the coefficient $a = 1.8$ and 0.5 corespoding to $n = 5$ and 20, respectively [2].

3.2. Line dynamic analysis

In the line dynamic analysis, the dynamic response of the FPU is still calculated as in the quasi-dynamic analysis, but the tension of the lines is calculated from a dynamic response of the lines. The mooring lines are meshed into elements along its length. The meshing of the mooring lines is automatically proposed but the user may also define the lengths of the elements. Meanwhile, with quasi-dynamic analysis, the line tension is only calculated at fairlead where the tension is maximum. In calculating the

line dynamic response, it is necessary to take into account the environmental load acting on the mooring line, due to the current profile that varies with water depth both in velocity and direction. Meanwhile, in quasi-dynamic analysis, the environmental load acting on the mooring line is ignored. Thus, it can be seen that the line dynamic analysis is more accurate than the quasi-dynamic analysis. Therefore, dynamic analysis also requires smaller time step, in order to find the maximum tension Tk of the simulation more accurately. The time step of line dynamic analysis is 0.02 s, while the time step of quasi-dynamic analysis is 1 s. So, fully line dynamic analysis with realizations during 3 h for all sea states takes a lot of time and computer potential. Therefore, this study uses the practice method of dynamic calculation using the "time window" to minimize computational time and capacity.

3.3. Selection of "time window" to study the dynamic response of mooring lines

Limiting dynamic analysis to a "time window" (Figure 3) is a useful method to minimize computational time. But the problem is how to determine the time duration, location, number of time windows for a dynamic simulation?

These windows are selected around the maximum tension values of $dTqs/dt$ in quasi-dynamic simulation during 3 hours. After practical studies [10,11], to mitigate this method, it is necessary to select a window around the maximum value of $dTqs/dt$.

The correlation between the peaks of the dynamic tension and the peaks of the quasi-dynamic tension dT_{qs}/dt allows to suggest a practical method for achieving the dynamic design tension of lines from the result of quasi-dynamic tension:

- Perform at least 5 quasi-dynamic simulations in 3 h of the most load-bearing line ($n = 5$);
- For each quasi-dynamic simulation, find out the maximum quasi-dynamic tension value;
- Around each of these maximum values, select a window (see Figure 3) whose interval is one low-frequency period to perform a dynamic simulation;
- For each dynamic simulation calculated in the time window, find the maximum value of dynamic tension (T_{dyn} max).

The line dynamic design tension is defined: T_D = average of T_{dyn} max + 1.8 standard deviations.
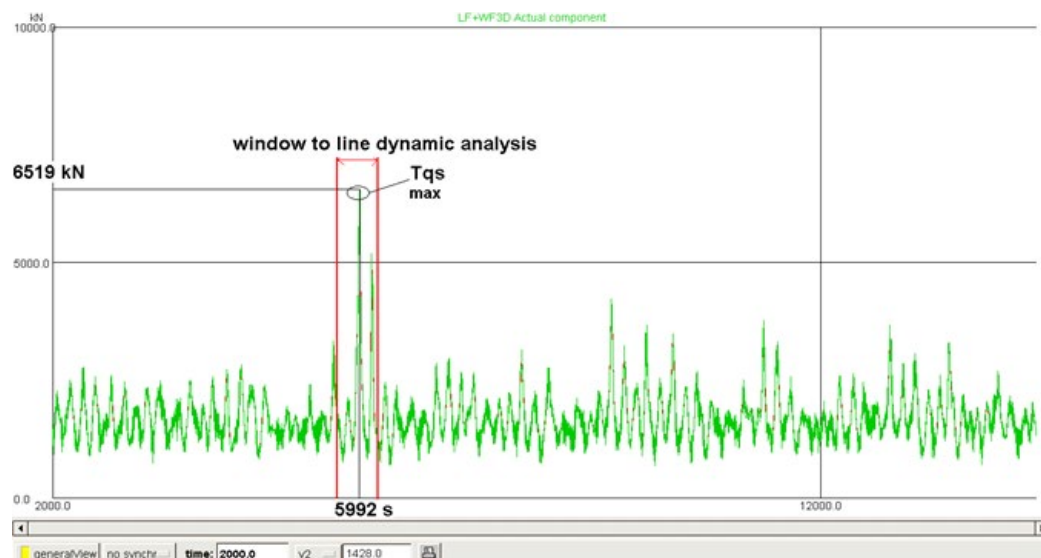
Figure 3. Selection of "time window" from quasi-dynamic simulation to line dynamic analysis.

3.4. Resistance safety factor of mooring line

After determining the design tension T_D of the mooring line, we calculate the resistance safety factor (SF) and evaluate the safety of the line compared to Bureau Veritas regulations [2]:

$$SF = \frac{T_{Br}}{T_D} \geq \left[SF\right] \tag{5}$$

Where T_{Br} is the minimum breaking load (MBL) of the line according to the manufacturer's catalog [14], depending on the material and diameter of the line; [SF] is the normative minimum safety factor. According to [2], with quasi-dynamic method [SF] = 1.75 and with dynamic method [SF] = 1.67 in intact condition. According to API [1], [SF] = 2.

3.5. Dynamic amplification factor of mooring line tension (DAF)

The purpose of determining the DAF (Dynamic Amplification Factor) is to evaluate the dynamic effect compared to the quasi-dynamic in the results of mooring line tension. The DAF is defined by the ratio between tension signals according to [3,10,11]:

$$DAF = \frac{T_{dyn} - T_{LF}}{T_{qs} - T_{LF}} \tag{6}$$

Where T_{LF} is a low frequency tension (T_{LF} = mean tension + low frequency tension variation); T_{qs} is a quasi-dynamic tension (T_{qs} = mean tension + low frequency tension variation + quasi-dynamic wave frequency tension); and T_{dyn} is a dynamic tension (T_{dyn} = mean tension + low frequency tension variation + dynamic wave frequency tension). Equation (6) is valid only if we take the T_{dyn} max, T_{qs} max, and T_{LF} at the same time, or at close times.

There is another formulation to calculate the DAF of mooring line tension according to [2,10]:

$$DAF = \frac{\sigma_{wfdyn}}{\sigma_{wfqs}} \tag{7}$$

Where σ_{WFdyn} is the standard deviation of time series simulation of line dynamic tension T_{WFdyn}; $T_{WFdyn} = T_{dyn} - T_{LF}$; and σ_{WFqs} is the standard deviation of time series simulation of line quasi-dynamic tension T_{WFqs}; $T_{WFqs} = T_{qs} - T_{LF}$.

Applications of DAF:

- Dynamic effect is evaluated through the DAF.

- Using the DAF to evaluate the resistance of mooring lines according to the dynamic method: first, we calculate the quasi-dynamic tensions for mooring lines, then select the most tension-bearing line to calculate the dynamic tension. We use the equation (5) to calculate the DAF for that line. Then we take the quasi-dynamic tensions of mooring line system multiplied by DAF to get the dynamic tensions for the entire mooring system.

4. Numerical application to evaluate the dynamic responses of mooring system of FPU DH-01

4.1. Simulation steps to calculate the dynamic tension of mooring line with ARIANE-3D

Applying the diagram in Figure 4, in the following application section, the authors perform the quasi-dynamic and dynamic response calculations for the mooring system of Dai Hung 01 semi-submersible platform (FPU DH01) at Dai Hung field according to [13], using the software of Bureau Veritas: HydroSTAR [4], ARIANE-3Dynamic and MCS-Cable [5].
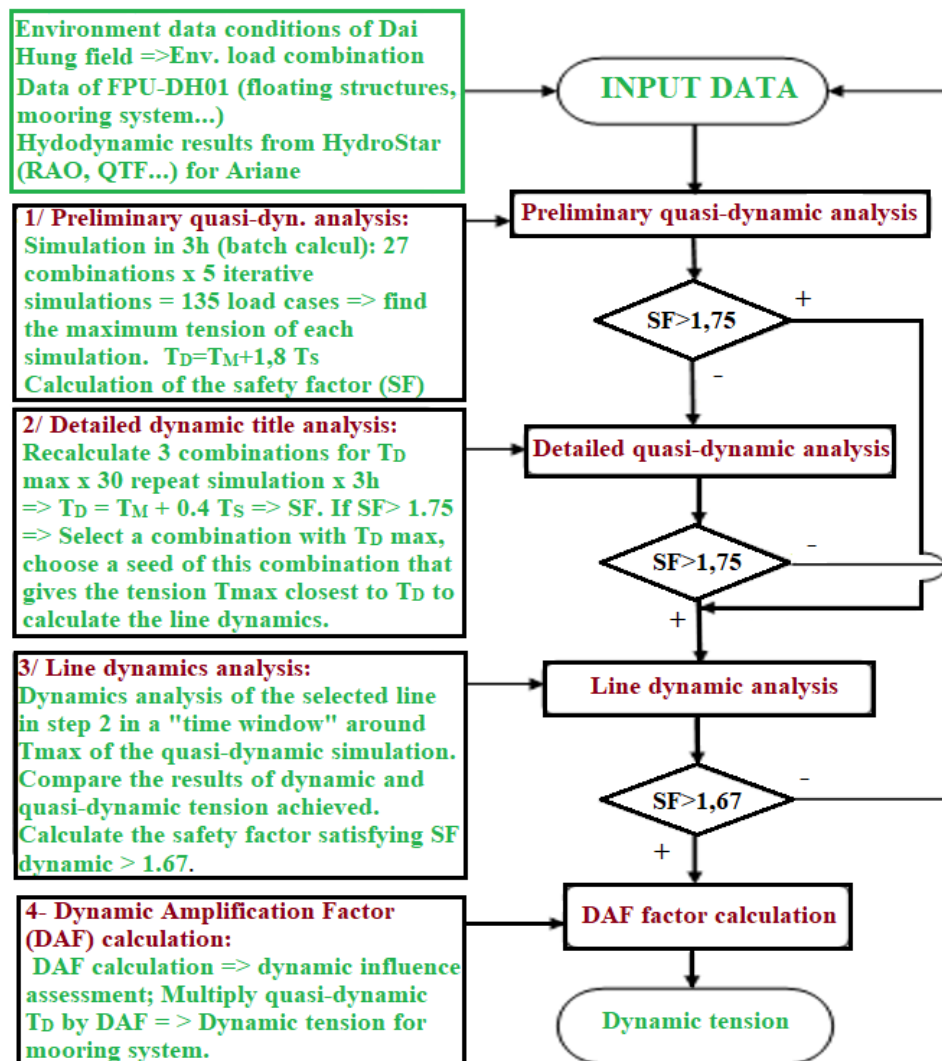
Figure 4. Practical calculation steps of dynamic response of mooring line with ARIANE-3D.

4.2. Data

Planning diagram of Dai Hung field with a water depth of 110 m is presented in Figure 5. The maximum random wave parameters with a 100-year return period taken in the Nord-Est direction (NE) which is the main direction of the impact wave at Dai Hung field. Environmental data in the NE direction according to [13] are as follows: Jonswap spectrum with spectral parameters: $\alpha = 0.0078$, $\gamma = 1.0504$, $\sigma_A = 0.1039$, $\sigma_B = 0.1079$. Significant wave height: $H_s = 10$ m; Period of peak spectral: $T_p = 15.96$ s; Average wind speed with return period of 100-year during 10': $V_w = 33.5$ m/s. Surface current velocity in SW direction (combined with NE wave direction): $V_c = 0.92$(m/s).

Data of FPU DH01 is taken according to [12]: Static weight is 10,866 tons ; FPU is structured according to AKER H-03 style, including: 02 pontons, 08 columns, cross braces, 8 oblique mooring lines: length of one mooring chain is 1,150 m, diameter 84 mm NVK4 RIG, the pre-tension is 70 tons, the minimum breaking load (MBL) of chains is 10,600 kN, linked to the seabed by 37-ton anchors of the Stevshark type.
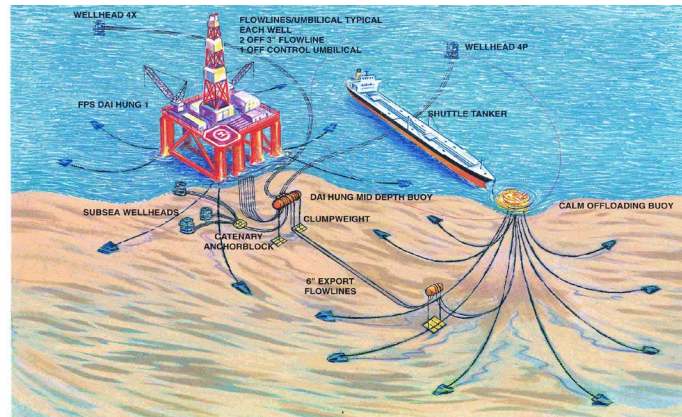
Figure 5. Dai Hung field schematic field lay-out [12].

4.3. Hydrodynamic analysis results using HydroStar for ARIANE calculation
Using HydroStar software and the theories in [4,6,7,8] to calculate the hydrodynamic force through the potential of incident, diffraction and radiation waves acting on semi-submersible platform. The outputs are RAO transfer functions of structural reactions (1st, 2nd order wave forces, motions of FPU…). These results are inputs to mooring line calculations using ARIANE software. The computational model image and some RAO results of the HydroStar software are showed in Figures 6 & 7.
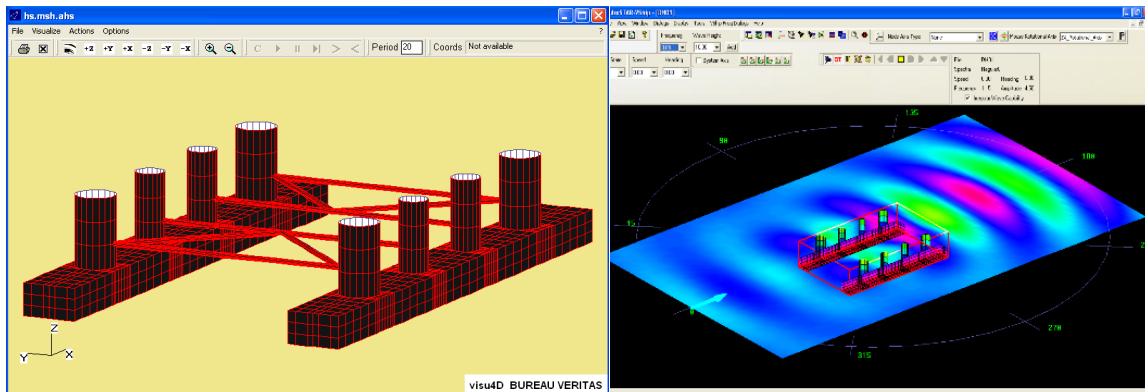

Figure 6. 3D meshing model (left) - Diffraction wave acting on the FPU (right) in HydroStar.
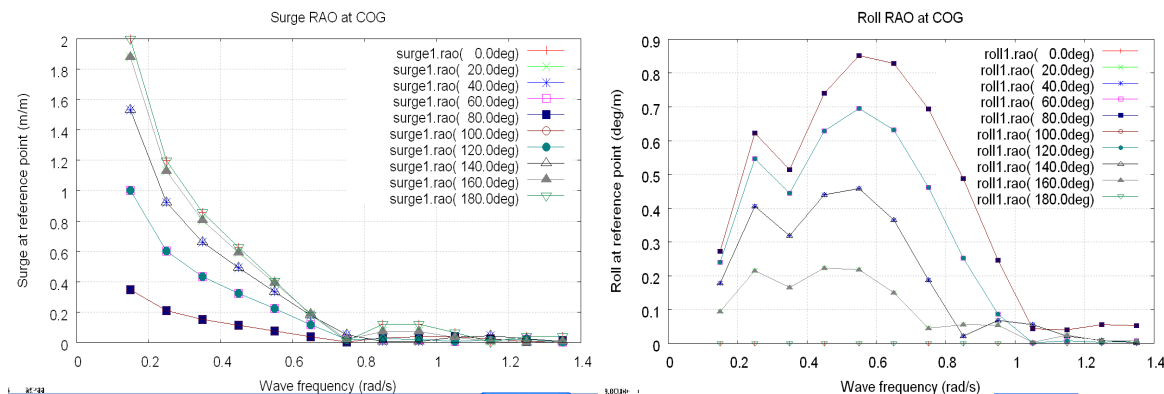

Figure 7. Surge RAO (left) - Roll RAO (right) of FPU DH01.

4.4. Dynamic calculation for the mooring system of FPU DH-01

4.4.1. Combination of extreme environmental parameters: Combinations of values: According to [2], there are two types of combinations: (1) Dominant wave; (2) Dominant current. In Vietnam's sea conditions, waves are dominant, so we combine the extreme wave parameters of 100 years with the wind and current speeds of 100 years multiplied by the reduction coefficient, which depends on the angle between wave and wind directions. Combinations of directions: As a rule [3], for a calculated direction (NE = 45°), it is necessary to account a variation of 22.5° around that direction for each type of impact load. So, we have the combinations: Wave = (45° ± 22.5°); Wind = (45° ± 22.5°); Current = (45°+22.5°). In total, we have 3x3x3=27 basic combinations (sea states). Each combination performs 5 iterative simulations in 3 hours, so there are 135 loading cases in total.

4.4.2. Quasi-dynamic tension calculation in time domain for 135 loading cases (batch): Calculate the design tensions (T_D) of the mooring system under the random wave loads for all loading cases (batch calculation) according to the quasi-dynamic method to find the most dangerous loading case for each mooring line. From there, calculate the safety factor (*SF*) and determine the line with the greatest tension in the mooring system to calculate in detail the quasi-dynamic simulation and dynamics for that line. Figure 8 shows a diagram and a 3D image of the mooring system of FPU DH01 modeling in ARIANE7.
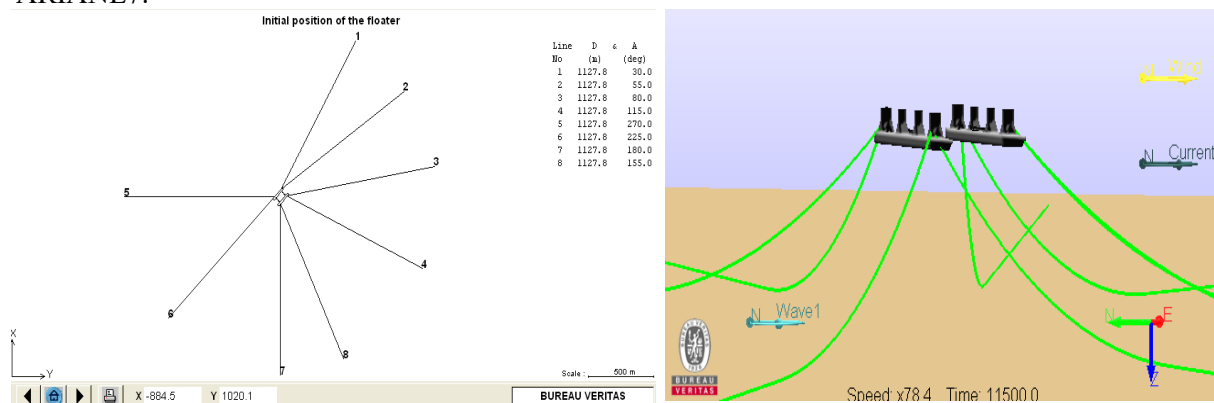
Figure 8. Modeling of FPU DH01's mooring system in ARIANE7.

The peaks T_k of the tension simulations output from ARIANE are processed and given T_D as shown in Table 1.

Table 1. Summarize the quasi-dynamic tension results of the mooring system in batch calculation.

Combination number	Line number	T_D max (kN)	Safety factor (SF)
6	5	1032.87	10.26
7	**8**	**2586.22**	**4.1**
9	6	564.19	18.79
20	7	1272.79	8.33
25	1	2148	4.93
	2	1064.39	9.66
27	3	568.99	18.63
	4	612.2	17.31

Comments: The lowest *SF* calculated by quasi-dynamic method for line 8 is *SF* min = 4.1 > [*SF*]=1.75. So, the mooring system is satisfying the durable condition. Line 8 has the largest design tension T_D, so it is necessary to calculate details according to single simulations for that mooring line.

Fourth Conference of Computational Methods & Ocean Technology

IOP Conf. Series: Materials Science and Engineering   1294 (2023) 012010

IOP Publishing

doi:10.1088/1757-899X/1294/1/012010

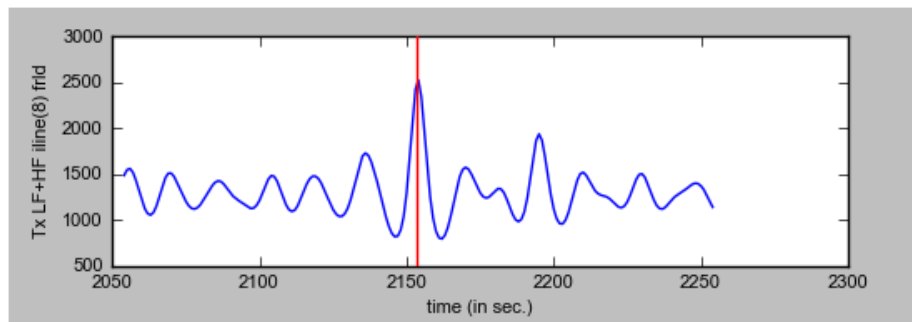*4.4.3. Single simulation of line tension in time domain:* Calculation steps as follow:

- *Step 1:* Quasi-dynamic simulation of 10,800 s for line 8 in combinations nº 7 with the seed 922 using ARIANE7 (Figure 9). The maximum longitudinal tension results $T_{x,max}$ = 2,527 kN at time t = 2,154 s.
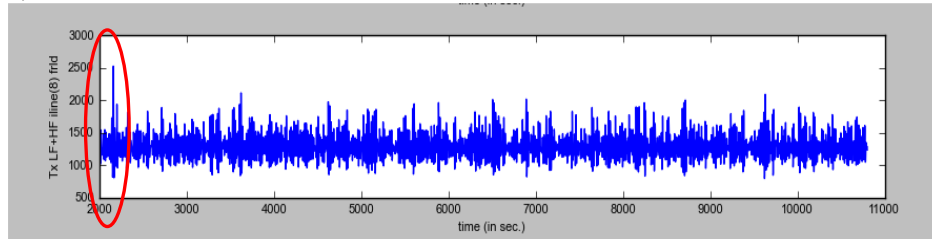
Figure 9. Quasi-dynamic tension simulation at fairlead of line 8 in 10,800 s using ARIANE7.

- *Step 2:* Select the "time window" of 200 s around $T_{x,max}$ of the simulation in step 1, recalculate the quasi-dynamic tension simulation in 200 s of line 8 with the same loading condition (Figure 10).

The results in the Figure 9&10 showed that the peak tension $T_{x,max}$ and the moment t of the peak were the same between the simulation in 10,800 s and the simulation in "time window" of 200 s around the peak. These results prove that the simulation method using time window is suitable.

Figure 10. Quasi-dynamic tension simulation at fairlead of line 8 in "time window" of 200 s.

- Step 3: Single simulation of line tension in time domain using ARIANE6.3. The reason for using ARIANE6.3 to recalculate the quasi-dynamic tension is this version 6.3 integrates with the MCS Cable 3D module to dynamic analysis of the mooring lines. Note: Due to the different conventions of 2 versions of ARIANE, line 8 in the ARIANE7 is line 5 in ARIANE6.3. Therefore, we simulate the quasi-dynamics tension of line 5 in 10,800 s with ARIANE6.3 (see Figure 11).
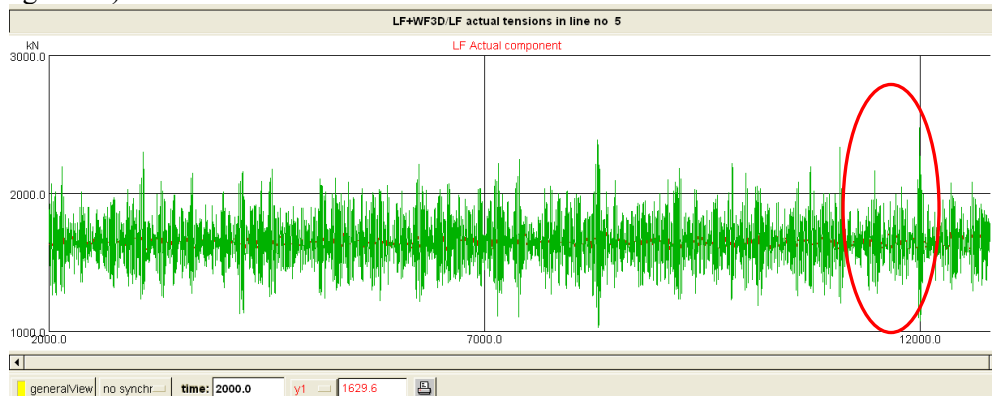
Figure 11. Quasi-dynamic tension simulation of line 5 in 10800s using ARIANE 6.3

4.4.4. Simulation of quasi-dynamic and dynamic tensions for line 5 in a " time window" of 200 s.
From the simulation in Figure 11, select a "time window" around the peak tension to recalculate the quasi-dynamic tension using ARIANE6.3 and dynamic tension using MCS Cable 3D. The results of these two software are shown in Figures 12. The results from Figure 12 show that T_{max} is of 2,475 kN at t = 11,992 s in quasi-dynamic and in dynamic simulation, T_{max} = 2,973 kN at t = 11,990 s.

T_{max} in quasi-dynamic < T_{max} in dynamic, so the dynamic influences need to be considered through the DAF. The time moment t of reaching T_{max} in two simulations is nearly identical, proving that the choice of "time window" around the T_{max} of quasi-dynamic tension for dynamic analysis is reasonable.

Then, we compare the quasi-dynamic and dynamic tension simulations of line 5 in a "time window" of 200 s in a same figure (see Figure 13). These two simulations in the Figure 13 are very similar, only differing in the magnitude of the tension. So, using DAF multiplied by quasi-dynamic tension to calculate the dynamic tension of the mooring system is suitable. Note that it's only necessary to determine the peak of simulation to calculate the design tension T_D from which to define the *SF*.

Safety factor of line 5 with dynamic tension: SF_{dyn} = 10,600/2,973 = 3.56 < $[SF]_{dyn}$ = 1.67, so the mooring system is satisfying the durable condition in dynamic analysis, according to [2].
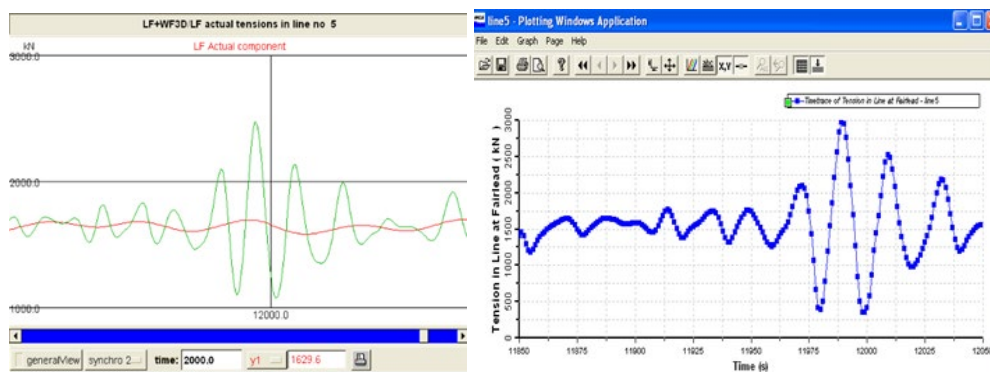

Figure 12. Quasi-dynamic tension (left) and dynamic tension simulations (right) of line 5 in 200 s.
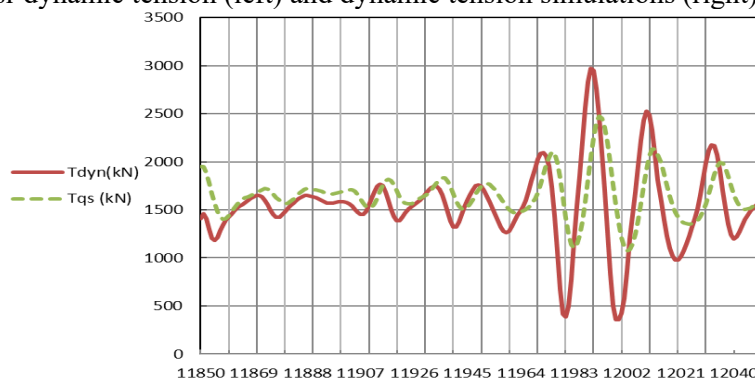

Figure 13. Comparison of quasi-dynamic simulation and dynamic simulation of line 5 in 200 s.

4.5. Dynamic amplification factor of mooring lines tension of FPU DH01 (DAF)
DAF is calculated by formula (6) or formula (7) in the section 3.5. In this application, we used formula (7) to calculate DAF. The DAF results for line 5 – the mooring line bearing the greatest tension in the most hazardous environment combination are shown in Table 2.

Table 2. Dynamic amplification factor of mooring lines tension of FPU DH01.

Line N_o – Load combination	"seed" N^o	σ_{WFqs} (kN)	σ_{WFqs} (kN)	DAF
Line 5- Combination 7	922	232.5846	232.5846	1.792

Comments: The dynamic effect of mooring line tension of the FPU DH01 at Dai Hung field with 110m of water depth is evaluated through a DAF of 1.792. From there, we can use the quasi-dynamic method to calculate the mooring lines, then multiply by the DAF to determine the dynamic tension, serving to evaluate the durability of the mooring line system.

5. Conclusions

In this study, a simplified practical method has been suggested to optimize the calculation time for dynamic analysis. Accordingly, it is possible to select a time window around the maximum quasi-dynamic tension to simulate the dynamic tension the mooring lines. The maximum quasi-dynamic tension is smaller than the maximum dynamic tension, indicating that the needs to define DAF for dynamic calculation. The times (t) when the tension reaches the maximum values in 2 simulations are nearly identical, demonstrating that it makes sense to choose the time window around the maximum quasi-dynamic value.

From the current case study presented in the paper, we found that for Vietnamese waters, oil and gas exploitation projects have a common water depth from about 50m to 100m, the calculated DAF coefficient is relatively small. It is not necessary to analysis fully dynamically for the mooring line. So, the similar projects in Vietnam may refer to the practical calculation steps presented in the paper to minimize calculation time while ensuring the accuracy of calculation results. The safety factors (*SF*) of the mooring lines of the FPU DH01 are greater than the permissible safety factor, according to [2]. Therefore, the design tensions of the mooring system satisfy the resistance condition for extreme sea states of the environment (ULS).

The results of dynamic responses of the mooring lines can be applied to verify the resistance of lines according to the dynamic calculation method, giving more accurate results than quasi-dynamic method. The next research is using the dynamic tension graph of the lines in a time series (with the input of a 1-year statistical wave load) to analyze dynamic fatigue for the mooring lines.

References

[1]   American Petroleum Institute 2005 Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures, API RP 2SK 3rd edition.

[2]   Bureau Veritas 2004 Classification of Mooring Systems for Permanent Offshore Units, Guidance Note NI 493 DTM R00 E, Paris.

[3]   Bureau Veritas 1998 Quasi-Dynamic Analysis of Mooring Systems using ARIANE software, Guidance Note NI 461 DTO R00 E, Paris.

[4]   Bureau Veritas User guide Ariane 7 (361p).

[5]   Bureau Veritas HydroStar For Experts – User Manual (176 p).

[6]   Chen X-B 2004 Hydrodynamics in Offshore and Naval Applications - Part I, *Paper presented at the 6th Int. Conference on Hydrodynamics*, University of Western Australia, Perth..

[7]   Chen X-B 1988 Étude des réponses du second-ordre d'une structure soumise à une houle aléatoire, *PhD. Thesis*, Université de Nantes (233p.).

[8]   Molin Bernard 2002 Hydrodynamique des Structures Offshore, Guides pratiques sur les ouvrages en mer. Editions Technip, Paris, France.

[9]   Pham H.H 2019 Methodology for total reliability evaluation of the mooring lines of floating offshore structures, *Proc. of the 1st VSOE2018*, ISBN:978-981-13-2305-8, 572-579.

[10]   Pham H.H 2015 FPSO - Fiabilité des lignes d'ancrage avec prise en compte de fatigue, ISBN: 978-3-8381-7928-5, 336 p., Presses Académiques Francophones.

[11]   Pham H.H 2009 Quasi-dynamic and line dynamic random analysis of mooring systems of FPSO

at White-tiger field using ARIANE-3D software, *Petro Vietnam J.*, **10**, 41-48.

[12]   PVEP 2006 DH 01-FPU Structural and Mooring Systems Drawings.

[13]   PVEP 2006 Final meteocean and environmental design criteria for Dai Hung fields, Report in VSP, Vietnam, 157p.

[14]   Vicinay – Mooring Lines Catalogue. Available at: Vicinay Mooring Connectors - Products catalogue (vicinayconnectors.com) (Accessed: 22.10.2023)