J Mar Sci Technol (2005) 10:53–60
DOI 10.1007/s00773-005-0196-z

Journal of
Marine Science
and Technology

Original articles

A stability analysis of tandem offloading systems at sea

Dong H. Lee and Hang S. Choi

Department of Naval Architecture and Ocean Engineering, Seoul National University, 56-1 Shinlim-dong, Kwanak-ku, Seoul 151-744, Korea

Abstract In this article, we analyze the linear stability of tandem offloading systems in wind, current, and waves. The wind and current forces are evaluated with the help of published experimental data, while the hydrodynamic coefficients and wave drift forces are rigorously estimated by using a three-dimensional singularity distribution method based on potential theory. The bow hawser and mooring lines are described quasistatically by elastic catenary equations. In order to examine the linear static and dynamic stability of the system, the equations for surge, sway, and yaw are linearized. The effect of design parameters such as turret position, mooring stiffness, and hawser length and stiffness on stability is investigated based on linearized model. The stability analysis clarifies the mechanism of the limit cycle for tandem offloading systems, which is known as fishtailing motion. The theoretical results of the shape and amplitude of the limit cycle are found to be in good agreement with those of simulations and experiments.

Key words Offloading systems · Tandem mooring · Single-point mooring · Nonlinear motion simulation · Linear stability analysis · Fishtailing motion

Introduction

Nowadays, turret-moored floating production storage and offloading (FPSO) systems are increasingly deployed for oil exploitation in deep-water marginal fields. The crude oil is normally transported by shuttle tankers, which are connected in tandem to the FPSO system through bow hawsers during the offloading process. Thus, the relative motion between the FPSO system and the shuttle tanker is a critical factor that determines a safe loading operation.

Address correspondence to: H.S. Choi (hschoi@snu.ac.kr)
Received: July 12, 2004 / Accepted: February 7, 2005

It is well known that moored vessels undergo large unstable drift motions even in mild sea-states. This unstable phenomenon is referred to in ship dynamics as fishtailing motion. This kind of motion occurs as a result of fluid–structure interactions. Similar phenomena in the field of aerodynamics are galloping and fluttering. Petrobras reported that shuttle tankers without a dynamic positioning system (DPS) must always be operated with the help of tugboats in Campos Basin.[1] Therefore, a stability analysis is necessary to design a safe mooring system, and mooring parameters such as mooring stiffness, turret position, hawser length, etc., must be carefully determined.

Numerous studies have been conducted on stability analysis and motion simulation of moored vessels. Bernitsas and co-workers[2–4] investigated design methodologies based on stability analysis and bifurcation theory for several mooring systems. Fernades and Sphaier[5] conducted research on this topic, and Simos et al.[6] studied the fishtailing motion of a single-point moored tanker, both theoretically and experimentally. Recently, some works on a tandem offloading system have been published.[7–9]

Here, we consider a FPSO–shuttle tanker system with a tandem configuration in current, wind, and waves. The wind and current forces were evaluated with the help of experimental data. Bow hawsers and mooring lines were modeled quasistatically. The hydrodynamic coefficients for moored vessels were rigorously estimated by using a singularity distribution method. Based on the Hartman–Grobman theorem and the stable manifold theorem, a stability analysis of the tandem offloading system was carried out. The bifurcation theory was applied to understand the features of dynamic stability. Then, the effects of environmental conditions and mooring parameters on the stability were examined in terms of the ratios between wind and current velocities, mooring stiffness, hawser length and tension.

The present approach can be applied to the case where environmental parameters come from different directions, but it is assumed in this study that these are all in the same direction, mainly because experimental data for current and wind loads on twin bodies are not yet available.

Nonlinear motion simulation

Equations of motion

A FPSO–shuttle tanker system is considered, as shown schematically in Fig. 1. To describe the motion of the FPSO–shuttle tanker system, two coordinates systems are introduced. Let *o–xy* be the body-fixed coordinate system with its origin located at the midship of each vessel, where the *x*-axis points to the bow. The *O–XY* system denotes the inertial coordinates fixed to the earth. For simplicity, only the horizontal plane motions (surge, sway, and yaw) are considered here.

The FPSO system is turret-moored, while the shuttle tanker is connected to the FPSO system through the bow hawser. In this figure, *a* denotes the distance of the turret position, and α, β, and l denote the distances of the attached positions and the length of the hawser, respectively. The mathematical model is derived from Newton's conservation law of linear and angular momentums. The nonlinear coupled equation of motion for each vessel is formulated in the corresponding body-fixed coordinate system.[10]

$$\mathbf{M}\dot{\mathbf{v}}_i + \mathbf{C}(\mathbf{v}_i)\mathbf{v}_i = \mathbf{F}_i(t)_{\text{memory}} + \mathbf{F}_i(t)_{\text{viscous}} + \mathbf{F}_i(t)_{\text{wind}} + \mathbf{F}_i(t)_{\text{current}} + \mathbf{F}_i(t)_{\text{wave}} + \mathbf{F}_i(t)_{\text{mooring}} + \mathbf{F}_i(t)_{\text{hawser}} \quad i = 1,2 \tag{1}$$

where $\mathbf{M}$ is the mass matrix including the added mass and added moment of inertia, $\mathbf{v}_i = [u_i, v_i, r_i]^{\mathrm{T}}$ is the velocity vector of the i-th vessel, and $\mathbf{C}(\mathbf{v}_i)\mathbf{v}_i$ represents the Coriolis and centripetal force and moment.

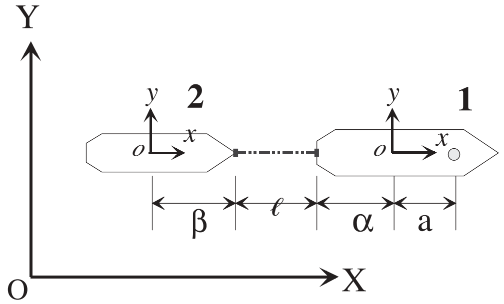

Fig. 1. Coordinate systems

The vessel's velocity is expressed in terms of the corresponding body-fixed coordinates, and relations to the inertial coordinates are made through the following equation:

$$\dot{\eta}_i = \begin{pmatrix} \dot{x}_i \\ \dot{y}_i \\ \dot{\psi}_i \end{pmatrix} = \begin{pmatrix} \cos\psi_i & -\sin\psi_i & 0 \\ \sin\psi_i & \cos\psi_i & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} u_i \\ v_i \\ r_i \end{pmatrix} \tag{2}$$

The external forces are composed of the wave radiation force, the viscous force, the wind force, the current force, the wave exciting force, the mooring force, and the bow-hawser force. The wave radiation force contains the memory effect, which is represented by a convolution integral of the so-called time–memory function. It is known that the time–memory function can be obtained effectively by using the hydrodynamic damping coefficients. The main contribution of the time–memory function to floater's motion is known as the increase in wave damping in the low-frequency range.[11]

$$\mathbf{F}_i(t)_{\text{memory}} = \int_{-\infty}^{t} \mathbf{L}(t-\tau)\mathbf{v}_i(\tau)\,\mathrm{d}\tau \tag{3}$$

The turret mooring system for the FPSO system consists of anchored chains. In this study, we considered 12 catenary-chain lines which were spread axisymmetrically. The dynamic effect of the mooring line was not included, and the restoring force was evaluated quasistatically by using the catenary equation. For time simulations, the relation between the vessel's offset and the restoring force was established, where the instantaneous touchdown points of the mooring lines were taken into account.

The bow-hawser force is generated as a result of extension, which is proportional to the distance between the FPSO system and the shuttle tanker. The elastic catenary equation is used for the bowhawser force. The horizontal distance is related to the tension, as given by[12]

$$d = \frac{Hl}{EA} + 2\frac{H}{w}\sinh^{-1}\left(\frac{wl/2}{H}\right) \tag{4}$$

where d is the horizontal distance between the FPSO system and the shuttle tanker, H is the horizontal component of the tension, w is the hawser weight per unit length, l is the hawser length, and E and A are the Young's modulus and the cross-sectional area of the bow hawser, respectively.

Environmental loads

The environmental loadings exerted on moored vessels are caused by current, wind, and waves. Wave forces contain first- and second-order components. The slow drift forces can invoke large horizontal responses of moored vessels. These wave forces can be calculated by using a singularity distribution method based on potential theory.[13]

In maneuvering models, current loads are included implicitly in the equations of motion in terms of the relative velocities between the vessel and the surrounding fluid. This approach is known to be more accurate than the method based on projected area and drag coefficients. However, maneuvering models require many hydrodynamic coefficients that are not easy to determine. In this study, we adopt the projected area and drag coefficients method. The current and wind forces can be expressed in the form

$$F = \frac{1}{2} C \rho V_r^2 A \tag{5}$$

where C is the drag coefficient, ρ is the water or air density, A is the projected area exposed to current or wind, and V_r is the relative velocity. In this study, the experimental data for VLCCs recommended by OCIMF are used for evaluating the current and wind loads. From Lee and Choi,[14] it can be seen that a shuttle tanker behind a FPSO system experiences sheltering effects. Some experimental results have indicated that the presence of a FPSO system stabilized the motion of shuttle tankers.[9] This can affect the dynamic behavior of tandem offloading systems. However, we did not include the sheltering effect here because published data are not available.

The vessel's motion induces viscous damping forces, which can readily be included into the current and wind loads by using the relative velocity concept for surge and sway motions. The drag moment resulting from pure yaw motion can be calculated with the cross-flow model expressed as

$$F_{mv} = -\frac{1}{2} \rho_{\text{water}} T \int C_D(x) x^2 |x| \mathrm{d}x \, r|r| \tag{6}$$

where $C_D(x)$ is the transverse drag coefficient for two-dimensional cross-flows, r is the yaw angular velocity, and x is the longitudinal coordinate measured from the midship.

Numerical results and discussion

For numerical simulations, we considered a typical FPSO–shuttle tanker system. The principal dimensions of the FPSO were 277 m (length) × 45.5 m (breadth) × 20 m (draft). For simplicity, let us assume that the dimensions of the shuttle tanker are the same as those of the FPSO. The submerged weight of a catenary chain-line is 2943 N/m. The stiffness of the turret mooring system is approximately 235 kN/m. The position of the turret system is taken as a design parameter. The elasticity of the bow hawser is 1.0E7 N and its length is also taken as a design parameter. The restoring force and the horizontal tension are given in Figs. 2 and 3. As can be seen from these figures, the hawser tension has strong nonlinear characteristics, while the mooring stiffness is almost constant in the region of small excursions.

It was assumed that the current, wind, and waves were all coming from the head direction of the FPSO, and that the current velocity was 0.5 m/s. The ratio between wind and current velocities ($\sigma = V_w/V_c$) was taken as a design parameter. As mentioned in the previous section, the sheltering effect between the FPSO system and the shuttle tanker is not considered in this study. It should be noted that a small disturbance was applied to the FPSO system in order to get the yaw motion started.

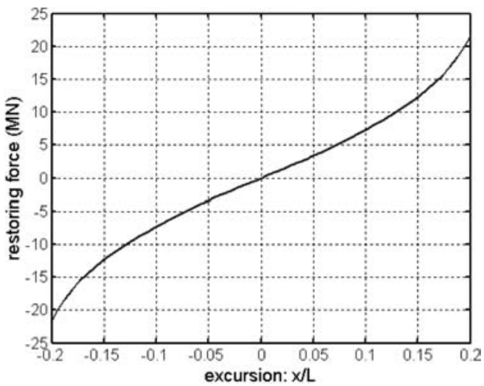

Fig. 2. Restoring force of the turret mooring system

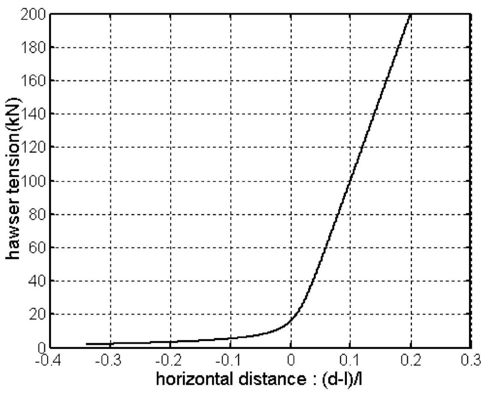

Fig. 3. Hawser tension

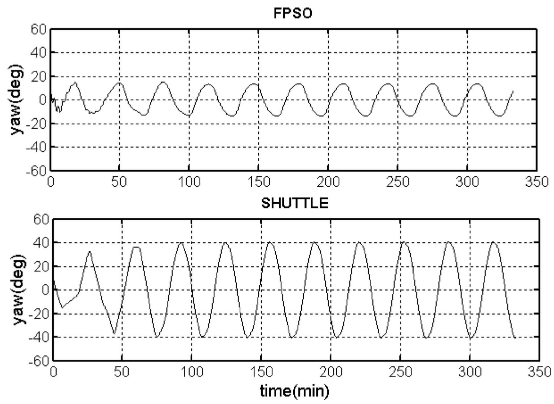

Fig. 4. Yaw motions of the FPSO–shuttle tanker system ($a = 0.2\,L$, $l = 0.6\,L$, $V_w = 10\,\text{m/s}$)

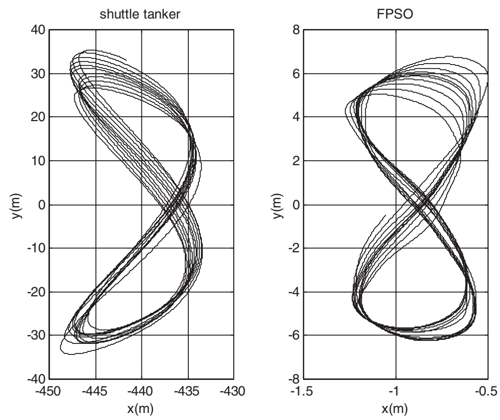

Fig. 5. Plane trajectory of the FPSO–shuttle tanker system ($a = 0.2\,L$, $l = 0.6\,L$, $V_w = 10\,\text{m/s}$)

Figure 4 shows the time-history of the yaw motions of the FPSO system and the shuttle tanker. In this case, the turret was located at $0.2\,L$ and the hawser length was $0.36\,L$, where L was the length of the FPSO, and the wind velocity was 10.0 m/s. A steady-state response corresponds to a large periodic oscillation, which is the fishtailing motion or limit-cycle motion discussed above. It was assumed that the nonlinear hawser tension and the viscous damping force are what prevent the eventual blowup of motion. The trajectories of the midship are plotted in Fig. 5, which shows a typical nonlinear behavior. The phase diagram is depicted in Fig. 6.

A typical stable motion is illustrated in Figure 7, where the turret position was $0.2\,L$, the hawser length was $0.18\,L$, and the wind velocity was 40.0 m/s. It should be noted that the yaw motion is very small, but can still be seen.

Based on the parameter study, the yaw amplitudes of the tandem offloading system can be summarized as

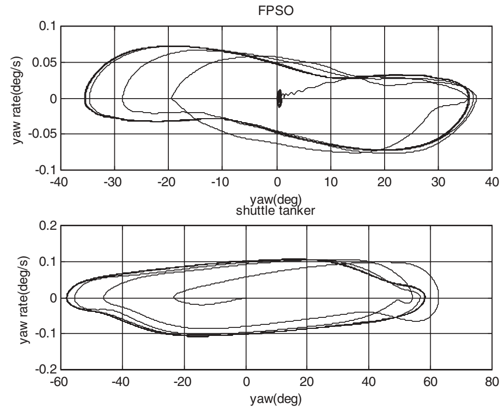

Fig. 6. Phase diagram of yaw motion ($a = 0.2\,L$, $l = 0.6\,L$, $V_w = 10\,\text{m/s}$)

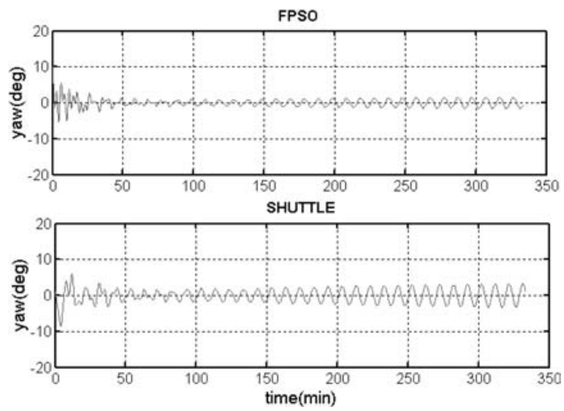

Fig. 7. Yaw motions of the FPSO–shuttle tanker system ($a = 0.2\,L$, $l = 0.2\,L$, $V_w = 30\,\text{m/s}$)

Table 1. Yaw amplitude of the FPSO

σ, l/L	0.2	0.4	0.6
0	43.0	38.0	35.7
20	16.4	13.3	12.6
40	4.3	4.0	3.4
60	1.6	1.8	1.8

Table 2. Yaw amplitude of the shuttle tanker

σ, l/L	0.2	0.4	0.6
0	58.3	60.0	62.1
20	40.4	40.5	41.5
40	9.9	10.8	11.1
60	3.2	3.9	4.1

shown in Tables 1 and 2. We found that the velocity ratio is the most important parameter for the yaw motion. Based on numerical simulations, a critical velocity ratio seems to exist between 20 and 40 because the yaw amplitude is significantly reduced, i.e., from 12.6° to 3.4° for the FPSO and from 41.5° to 11.1° for shuttle tanker, as shown in Tables 1 and 2.

Stability analysis

Linearized equations of motion

In order to clearly understand the dynamic behavior of mooring systems, a stability analysis must be carried out. To perform this analysis, we must first find the equilibrium points of nonlinear equations of motion, and the equations must be linearized near these equilibrium points. The equilibrium points can be obtained from the static force and moment balance between the steady environmental loads and the mooring forces. The equilibrium point of the shuttle tanker is determined from the relations

$$F_0 \cos(\psi_2 - \gamma) = -X_2(\psi_c, \psi_w, \psi_2) \tag{7a}$$

$$F_0 \sin(\psi_2 - \gamma) = Y_2(\psi_c, \psi_w, \psi_2) \tag{7b}$$

$$\beta F_0 \sin(\psi_2 - \gamma) = N_2(\psi_c, \psi_w, \psi_2) \tag{7c}$$

where γ and F_0 are the hawser angle and tension, ψ_c and ψ_w are the incident angles of the current and wind, respectively. (X, Y, N) denote the steady forces and moment due to wind, current, and waves. The above equations can be formulated as

$$\beta Y_2(\psi_c, \psi_w, \psi_2) = N_2(\psi_c, \psi_w, \psi_2) \tag{8}$$

$$F_0^2 = X_2^2 + Y_2^2 \tag{9}$$

The heading angle of the shuttle tanker and the hawser tension are calculated from Eqs. 8 and 9. It should then be confirmed that the equilibrium point of the FPSO system satisfies the condition

$$(a+\alpha)F_0 \sin(\psi_1 - \gamma) + aY_1(\psi_c, \psi_w, \psi_1) = N_1(\psi_c, \psi_w, \psi_1) \tag{10}$$

Assuming that the mooring stiffness and the hawser tension are constant and ignoring the quadratic viscous damping force, the linearized equations of motion for surge, sway, and yaw are derived as[14]

$$\begin{bmatrix} \mathbf{M}_{11} & 0 \\ 0 & \mathbf{M}_{22} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{x}}^1 \\ \ddot{\mathbf{x}}^2 \end{bmatrix} + \begin{bmatrix} \mathbf{S}_{11} & \mathbf{S}_{12} \\ \mathbf{S}_{21} & \mathbf{S}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{bmatrix} = 0 \tag{11}$$

where

$$\mathbf{M}_{ii} = \begin{bmatrix} m_{11}^i & 0 & 0 \\ 0 & m_{22}^i & m_{26}^i \\ 0 & m_{62}^i & m_{66}^i \end{bmatrix}$$

$$\mathbf{S}_{11} = \begin{bmatrix} K + K_H & 0 & 0 \\ 0 & K + \frac{F_0}{l} & aK - \frac{F_0}{l}(\alpha + l) - \frac{dY_1}{d\psi_1} \\ 0 & aK - \alpha\frac{F_0}{l} & a^2K + \alpha\frac{F_0}{l}(\alpha + l) - \frac{dN_1}{d\psi_1} \end{bmatrix}$$

$$\mathbf{S}_{12} = \begin{bmatrix} -K_H & 0 & 0 \\ 0 & -\frac{F_0}{l} & -\beta\frac{F_0}{l} \\ 0 & \alpha\frac{F_0}{l} & \alpha\beta\frac{F_0}{l} \end{bmatrix}$$

$$\mathbf{S}_{21} = \begin{bmatrix} -K_H & 0 & 0 \\ 0 & -\frac{F_0}{l} & \alpha\frac{F_0}{l} \\ 0 & -\beta\frac{F_0}{l} & \alpha\beta\frac{F_0}{l} \end{bmatrix}$$

$$\mathbf{S}_{22} = \begin{bmatrix} K_H & 0 & 0 \\ 0 & \frac{F_0}{l} & \frac{F_0}{l}(\beta + 1) - \frac{dY_2}{d\psi_2} \\ 0 & \beta\frac{F_0}{l} & \beta\frac{F_0}{l}(\beta + 1) - \frac{dN_2}{d\psi_2} \end{bmatrix}$$

where subscripts 1 and 2 represent the FPSO system and the shuttle tanker, respectively, **M** is the mass matrix that includes added mass, **S** is the restoring stiffness matrix, K is the turret-mooring stiffness, and F_0 and K_H denote the hawser tension and the axial stiffness, respectively. The definitions of α, β, a, and l are given in Fig. 1.

Static and dynamic stability

Based on the Hartman–Grobman theorem and the stable manifold theorem, the local behavior of the nonlinear equation near an equilibrium point should be determined by its linearized equation. Static stability is indicated by the fact that the restoring moment induced by environmental loads is positive at static equilibrium points. That means that the determinant of the stiffness matrix $det[\mathbf{S}]$ should be positive. The stable condition for the FPSO–shuttle tanker system requires the following inequality to be satisfied.

$$\frac{F_0}{l}\left(-\frac{dN_2}{d\psi_2}+\beta\frac{dY_2}{d\psi_2}\right)K\left(-\frac{dN_1}{d\psi_1}+a\frac{dY_1}{d\psi_1}+aF_0+\alpha F_0\right)>0 \tag{12}$$

Note that the static stability is not affected by the presence of the FPSO system. Generally, the shuttle tanker with a single point mooring system satisfies the static stability criteria and keeps its heading stable in this state.

$$\frac{F_0}{l}\left(-\frac{dN_2}{d\psi_2}+\beta\frac{dY_2}{d\psi_2}\right)>0 \tag{13}$$

For the static stability of the FPSO–shuttle tanker system, the turret position, a, must be located forward of the critical turret position.

$$a_{cr}=\frac{\dfrac{dN_1}{d\psi_1}-\alpha F_0}{\dfrac{dY_1}{d\psi_1}+F_0} \tag{14}$$

The above equation indicates that the shuttle tanker connected to the FPSO system causes the critical point to be moved closer to the mid ship and enhances the static stability.

Dynamic stability is determined in terms of design parameters such as a, K, l, and F_0, which govern the restoring stiffness matrix, **S**. The stability can be examined by checking the Eigenvalues of Eq. 11.

$$\mathbf{x}(t)=\mathbf{X}e^{\lambda t} \tag{15}$$

The sign of the Eigenvalues provides us with information on the features of the nonlinear dynamics. In particular, if there exists a complex conjugate pair of Eigenvalues with a positive real part, the equilibrium point will be unstable with a two-dimensional unstable manifold. Then motions asymptotically reach a periodic oscillation, which is referred to as limit cycle.

Note that the restoring stiffness matrix, **S**, is not symmetrical. This asymmetry of the restoring stiffness matrix is generated by interactions between fluid loading and mooring stiffness, and may produce unstable motions in moored vessels, such as fishtailing motion.

Numerical results and discussion

As a case study, we considered the same FPSO–shuttle tanker system as in the previous section. Here again we assume that current, wind, and waves are all coming from the same direction. Figure 8 shows the stability diagram of the FPSO–shuttle tanker system. The hawser tension (F_0) is normalized by the longitudinal drag force (F_e) caused by current and wind. The hawser length is normalized by the length of the vessel. σ denotes the ratio between the wind and current velocities. Figure 9 shows the stability diagram of a single-point-moored shuttle tanker, which confirms that a relatively short bow hawser suppresses the unstable motion of an SPM system. However, the tandem offloading system displays quite different phenomena from those of the SPM. For a tandem offloading system, a short hawser cannot guarantee stability, as demonstrated in Fig. 8.

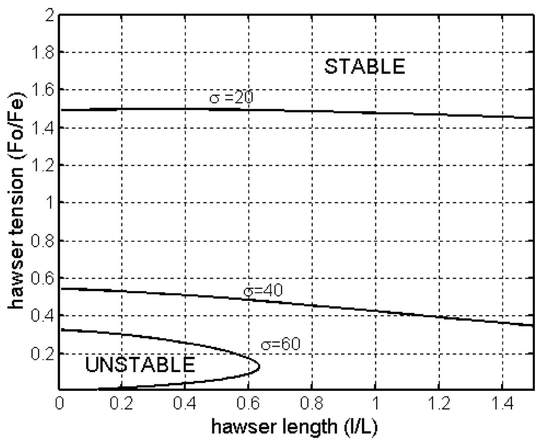

Fig. 8. Stability diagram for the TANDEM system as a function of hawser tension and length

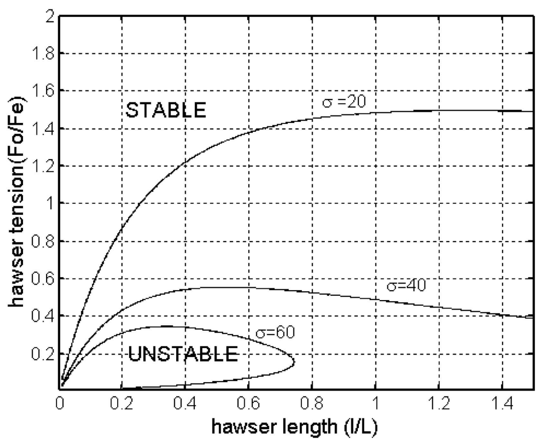

Fig. 9. Stability diagram for the SPM system

It can easily be seen from Figs. 8 and 9 that σ, the ratio between the wind and current velocities, is the most important parameter determining the stability of a mooring system.

In addition, the wind load tends to stabilize the system owing to the presence of the deckhouse at the stern, which induces a positive restoring moment, as seen in the OCIMF data.

Figures 10 and 11 clearly demonstrate the effect of the turret mooring stiffness and location on the stability

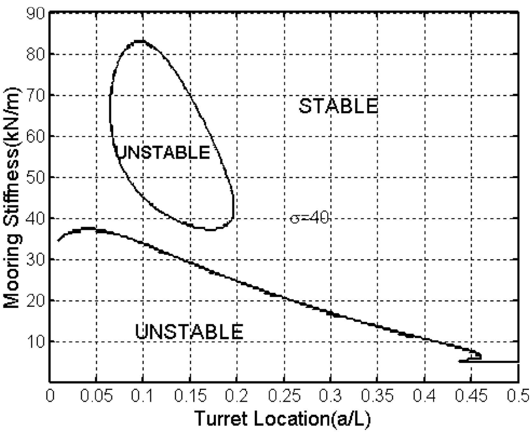

Fig. 10. Stability diagram for the TANDEM system as a function of the mooring stiffness and turret location

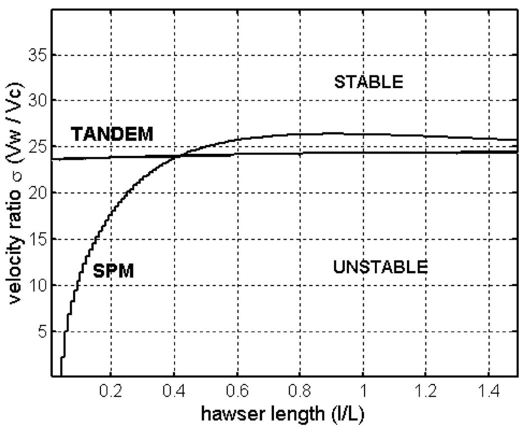

Fig. 12. Stability diagram for the tandem and SPM systems as functions of the velocity ratio and hawser length

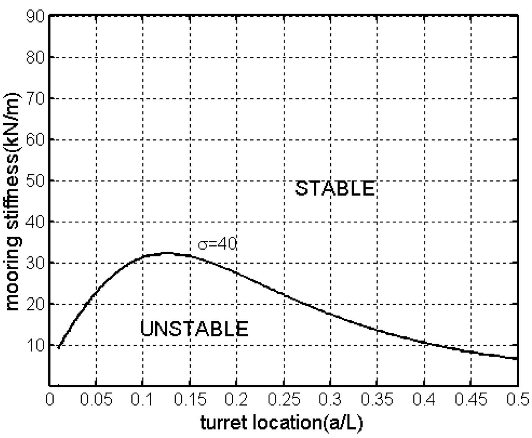

Fig. 11. Stability diagram for the TURRET system

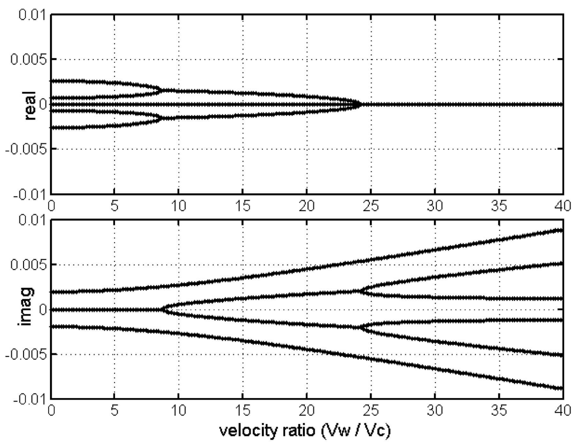

Fig. 13. Variation in Eigenvalues depending on the velocity ratio

of the offloading system. However, only one wind velocity is considered here in order to avoid the confusion that may be caused by the complicated stability boundary lines. It is confirmed that the wind load tends to enlarge the unstable region in the case of the turret mooring system, as opposed to the SPM. For the tandem offloading system, an unstable island exists for relatively strong mooring stiffnesses. This result is believed to have been caused by the interaction between the FPSO system and the shuttle tanker. Thus, the mooring stiffness and the location of the turret must be determined carefully.

Figure 12 shows the critical wind velocity for different hawser lengths. For the tandem offloading system, the stability boundary is not sensitive to hawser length. From this study, it is found that the tandem offloading system considered here is always unstable in weak winds.

In order to examine the occurrence of limit cycles, Eigenvalues depending on the velocity ratio are plotted, as shown in Fig. 13. It can be seen that there is a complex conjugate pair of Eigenvalues with a positive real part when the velocity ratio is less than 24. This velocity ratio corresponds to a Hopf bifurcation point. It is known that the fishtailing motion occurs when the wind velocity is below the critical value. In fact, this is expected from the nonlinear simulations which are summarized in Tables 1 and 2.

Conclusion

In this study, the stability of a tandem offloading system was studied when the environmental parameters were all in the same direction. Simulations of the nonlinear motions of moored vessels under the action of wind, current, and waves were performed to investigate the motion response in a more realistic manner. Numerical simulations showed that the tandem offloading system experiences large fishtailing motions even in a light wind. It was found that the velocity ratio between wind and current is the most important parameter, while the stability is not so sensitive to the hawser length.

Using the Hartman–Grobman theorem and the stable manifold theorem, a stability analysis of the tandem offloading system was carried out based on the linearized equations of motion. Bifurcation theory was used to examine the overall features of the dynamic stability. The parameter space consisted of the hawser length and tension, the turret mooring stiffness and location, and the velocity ratio between wind and current. The stability diagram of the tandem offloading system is quite different from those of a single-point-moored shuttle tanker and a turret-moored FPSO system. In the case of a tandem offloading system, the hawser length does not affect the stability significantly, whereas turret mooring can worsen the stability depending on its stiffness.

In order to clarify the fishtailing motion more accurately, further study needs to be carried out to find the solution for fully nonlinear equations of motion.

References

1. Sphaier SH, Fernandes AC, Correa SHS, et al (2001) Maneuvering model for FPSOs and offloading analysis. 20th International Conference on Offshore Mechanics and Artic Engineering, Rio de Janeiro
2. Bernitsas MM, Papoulias FA (1990) Nonlinear stability and maneuvering simulation of single point mooring systems. 1st Offshore Station Keeping Symposium, Houston, Texas
3. Chung JS, Bernitsas MM (1997) Hydrodynamic memory effect on stability, bifurcation, and chaos of two-point mooring systems. J Ship Res 41:26–44
4. Bernitsas MM, Kim BK (1998) Effect of slow-drift loads on nonlinear dynamics of spread mooring system. J Offshore Mech Arctic Eng 120:201–211
5. Fernandes AC, Sphaier S (1997) Dynamic analysis of FPSO system. 11th International Offshore and Polar Engineering Conference
6. Simos AN, Tannuri EA, Aranha JAP, et al (2001) Theoretical analysis and experimental evaluation of the fishtailing phenomenon in a single-point moored tanker. 11th International Offshore and Polar Engineering Conference, vol 1, pp 369–374
7. Morishita HM, Cornet BJJ (1998) Dynamics of a turret-FPSO and shuttle vessel due to current. IFAC Conference CAMS '98, Fukuoka
8. Lee DH, Choi HS (2000) A dynamic analysis of FPSO–shuttle tanker system. 10th International Offshore and Polar Engineering Conference, vol 1
9. Fucatu CH, Nishimoto K, Maeda H, et al (2001) The shadow effect on the dynamics of a shuttle tanker. 20th International Conference on Offshore Mechanics and Artic Engineering, Rio de Janeiro
10. Fossen TI (1994) Guidance and control of ocean vehicles, Wiley
11. Choi YR, Choi HS (1991) Transient surge motion of a moored ship in random waves. J Offshore Polar Eng 1:239–241
12. Irvine M (1981) Cable structures. Dover Publications, New York
13. Pinkster JA, van Oortmerssen G (1977) Computation of the first- and second-order wave forces on oscillating bodies in regular waves. 2nd International Conference on Numerical Ship Hydrodynamics, pp 136–156
14. Lee DH, Choi HS (1998) The motion behavior of the shuttle tanker connected to a turret-moored FPSO. Proceedings of the 3rd International Conference on Hydrodynamics, pp 173–178