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Behaviour of Mooring Systems for Different Line Pretensions

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Abstract. Mooring lines are the most commonly used station-keeping systems for floating platforms as they are easy to install and relocate. The mooring lines are usually pre-tensioned so as to use their energy absorption to reduce the platform motions and thereby, to lower the forces in the lines. To decide on the preliminary design of the platforms, it is necessary to investigate the restoring behaviour of the mooring systems for various parameters. In this study, two different mooring configurations with and without mooring line in wave heading direction are considered for determining its behaviour for various pretensions in the lines. A MATLAB code named *QSAML* has been developed using quasi-static approach to compute the restoring forces of the mooring system. The code is validated with experimental tests and used in this study. It has been observed that with increase in pretension of the mooring line, restoring performance of the mooring system can be improved. The maximum permissible excursions by mooring system in the wave heading direction are found to be more for relatively lower pretension values.

Introduction

In recent years, the oil exploration and production companies have started increasing their operational scope from shallow waters to deep and ultra-deep waters in order to meet the oil demand-supply equity. Hence, the initiative to exploit reserves in deep-waters has led the researchers to extend the limits of station-keeping systems for the offshore floating platforms. Among the different types of mooring systems, the spread moorings are preferred as they have long service life and can be used for all sizes of the platform at any water depths.

The mooring lines are usually multi-component catenary anchor lines, attached to the hull of the platform near its centre of pitch for low dynamic loading [1]. These catenary mooring lines are pre-tensioned and typically subjected to the loads caused by the wave frequencies and vessel motions [9]. Hence, there is a need to incorporate the dynamic considerations in the analysis/design procedure of the deep-water mooring systems. The quasi-static approach which has been proven to be a proper design tool for the mooring systems is considered in the first approach. Quasi-static analysis is almost certain to achieve convergence and if desired, further analysis may then be carried out using the output of this analysis as initial conditions for the dynamic analysis [5, 6, 7, and 8].

The study in this paper includes developing a numerical code for the analysis of multi-component catenary mooring lines using quasi-static approach, which after validation with the experimental results, is used to conduct a parametric study on the behaviour of the mooring systems for various line pretensions.

Governing Equations for the Mooring Line Analysis

The relationship between the restoring force and horizontal excursion of a mooring line is nonlinear and requires an iterative solution. The key assumptions made for the analysis of mooring lines are – (a) components of the mooring line move very slowly so that the drag forces on the line can be treated as negligible; (b) change in the line geometry is insignificant and thereby the in-line force due to direct fluid loading caused from the waves is also insignificant; (c) the clump weight segment is inextensible; and (d) only horizontal excursion of the line is considered.

Using equation of a catenary for the evaluation of force-excursion relationship of the mooring line, the vertical and horizontal projection of any segment hanging freely under its own weight *w* per unit length, is as given in Eq. 1, Eq. 2.

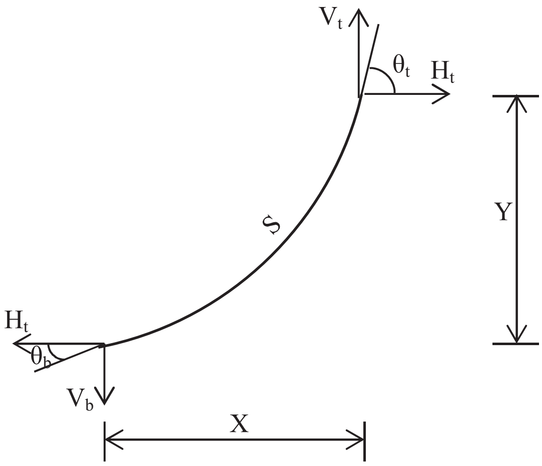

Fig. 1 Free body diagram of a freely suspended mooring line

$$Y=\frac{H_t}{w}[\cosh\{\sinh^{-1}(\tan(\theta_t))\}-\cosh\{\sinh^{-1}(\tan(\theta_b))\}] \quad (1)$$

$$X=\frac{H_t}{w}[\sinh^{-1}(\tan(\theta_t))-\sinh^{-1}(\tan(\theta_b))] \quad (2)$$

The extension of any segment under increased line tension can be evaluated using Eq. 3. Let the initial average line tension be T_0 when the segment length is S_0 and for increased average line tension T, the stretched length becomes:

$$S=S_0\left(1+\frac{T-T_0}{EA}\right) \quad (3)$$

The analysis has been carried out for the mooring line with disturbed clump weight by referring to the procedure steps mentioned in [1]; incorporating the two conditions stated for lifting-off of the clump weight. The behaviour of the mooring system i.e. the resultant horizontal force H, for an excursion δ can be computed using the Eq. 4.

$$H(\delta)=\sum_{j=1,p} H_j(\delta_j)\cos(\pi-\theta_j) \quad (4)$$

where p is the total number of mooring lines; θ_j is the angle between the j^{th} mooring line and the direction of excursion; δ_j is the excursion for the j^{th} mooring line; $H_j(\delta_j)$ is the associated horizontal force with $\delta_j=\delta\cos(\pi-\theta_j)$.

Numerical Modelling of the Mooring Lines

Pretension installed in the mooring lines has an appreciable impact on the design of the floating structure as this tension at the fairleads shall be incorporated in the platform structure design. Hence, it is very essential to study the effect of pretension on the performance of mooring systems and install optimum pretension in the mooring lines.

To compute the restoring forces in mooring lines for various pretension values, quasi-static approach is adopted for the analysis and a MATLAB code named *QSAML* has been developed. The numerical code is validated with experiment tests by comparing the mooring stiffness curve obtained for the mooring configuration-I (MARLIN truss spar) given in Table 1.

For the parametric study, a floating platform having the fairleads at a height of 988m from the sea bed is considered. Two mooring configurations as shown in Fig. 2: I) nine lines arranged in three groups with one line group in wave heading; and II) ten lines arranged in four groups with no line group in wave heading, are chosen. To study the effect of pretension, configurations: I and II as given in Table 1, are investigated for pretension values ranging from 1.8×10^3 to 6.5×10^3kN. The material properties – wet weight, effective modulus, breaking loads and lengths of the various components of the mooring line are as given in Table 2.

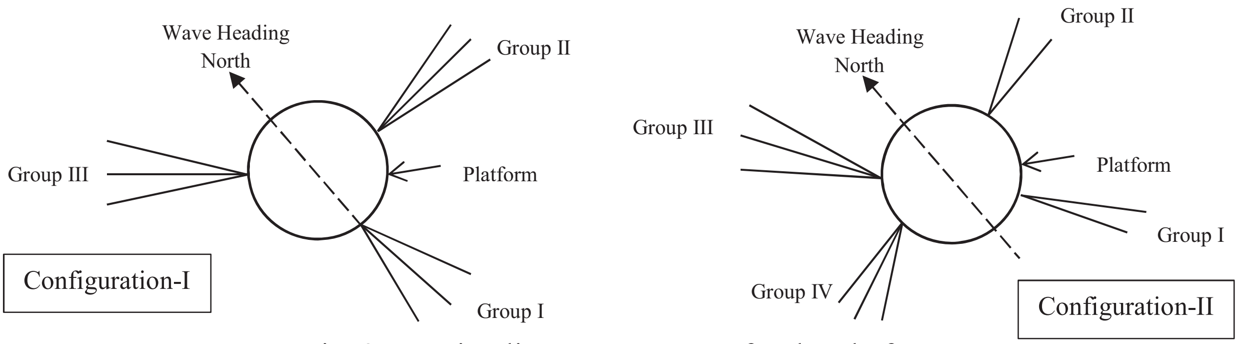

Fig. 2 Mooring lines arrangement for the platform

Table 1 Mooring line configurations
(Azimuth angles are mentioned with respect to *wave heading south*)

Group	Configuration-I	Configuration-II
I	0^0, 5^0, 5^0	45^0, 50^0
II	115^0, 120^0, 125^0	125^0, 132.5^0
III	235^0, 240^0, 245^0	222.3^0, 229.7^0, 235^0
IV	–	308.5^0, 314.1^0, 320.3^0

Table 2 Characteristics of the mooring line

Legend	Top Component	Middle Component	Lower Component
Type	Chain cable	Steel strand cable	Chain cable
Length (m)	76.2	1828.7	45.7
Wet weight (kN/m)	2.73	0.636	2.73
Effective Modulus (kN)	665852	1338848	858882
Breaking load (kN)	13188	12454	13188

Results and Discussion

The results obtained from numerical code, *QSAML* and experiments tests for mooring configuration-I are as shown in Fig 3. The experimental tests were performed on a 1:61 scale truss spar model by Amooc in Offshore Technology Research Centre (OTRC) wave tank at Texas A&M University [10]. The difference in the results can be attributed to change in the mooring line set up between the prototype and experimental model i.e. the prototype is considered with nine mooring lines whereas experimental model with only five mooring lines (one line from group: I, III and three lines from group-II); which otherwise can be concluded that there is a good agreement between the numerical and experimental results.

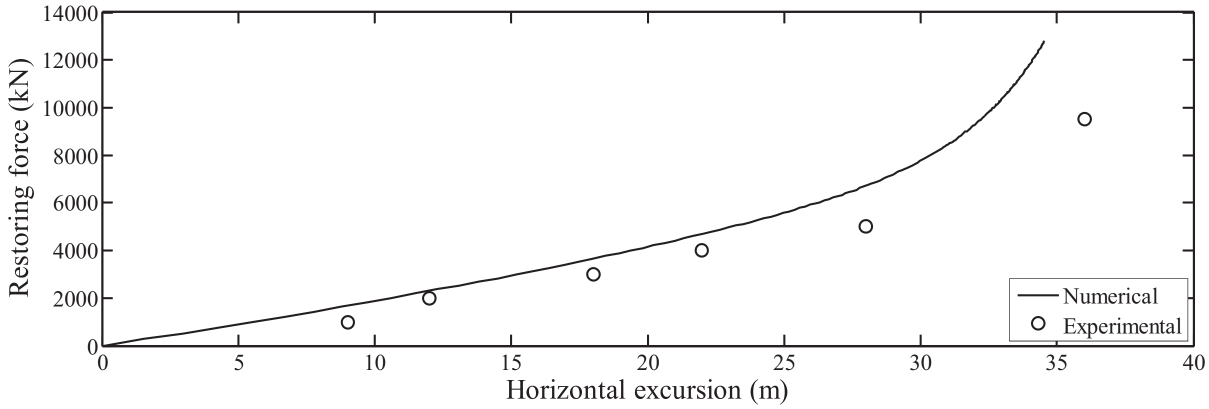

Fig. 3 Validation of numerical predictions with experimental measurements

From Figs. 4 and 5, it can be inferred that for any excursion of the platform, mooring system restoring force increases with increase in the line pretension for both configurations. For example, considering the mooring configuration-I at an excursion of 10m, the lines when installed with pretension 1.8×10^3kN offered lowest restoring force of 0.04×10^4kN whereas when installed with pretension 2.5×10^3kN offered higher restoring force of 0.28×10^4kN and so on.

Maximum permissible excursions of the two mooring systems for various line pretensions are as given in Fig. 6. It can be inferred that the maximum permissible excursion by the two mooring system configurations decreases as the line pretension is increased. These maximum excursions are found to be more for relatively lower line pretensions. For pretensions 1.8×10^3kN to 2.0×10^3kN, the mooring systems can permit excursions ranging from 52m to 114m to the platform in wave heading and for pretensions 2.1×10^3kN to 6.5×10^3kN, the maximum permissible excursions of the mooring systems range from 6m to 38m.

The reduction in maximum permissible excursions is more for relatively lower line pretensions and is less for relatively higher line pretensions. For pretensions 1.8×10^3kN to 2.1×10^3kN, the reduction ranges from 13m to 30m and for pretensions 2.1×10^3kN to 6.5×10^3kN, the reduction ranges from 0.3m to 8m.

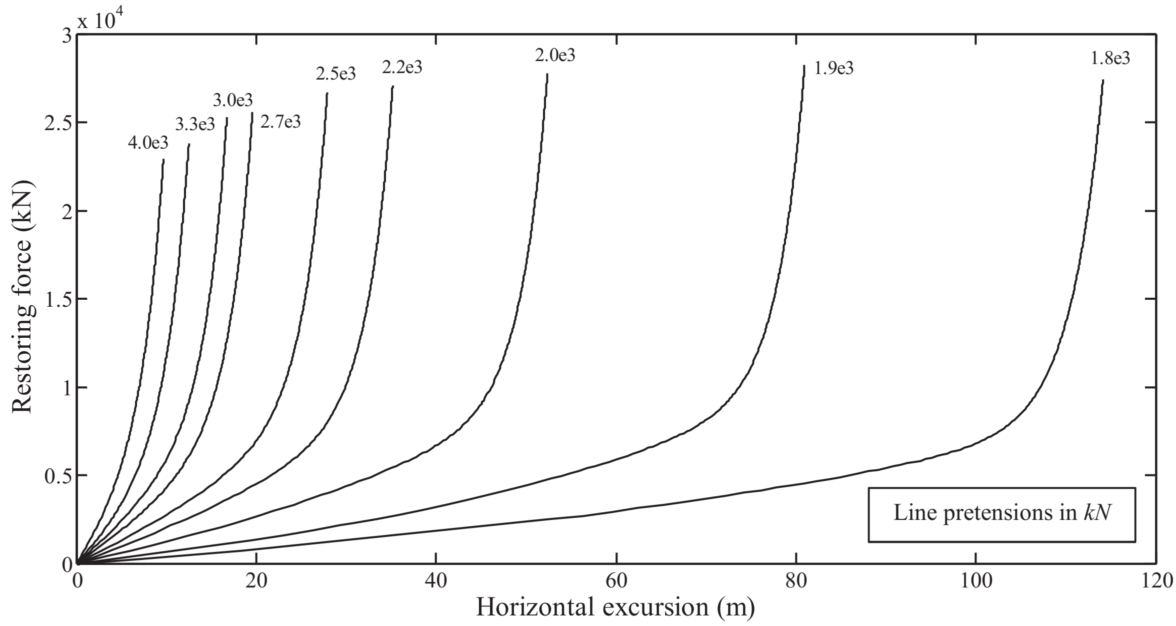

Fig. 4 Variation of the restoring force in configuration-I for different line pretensions

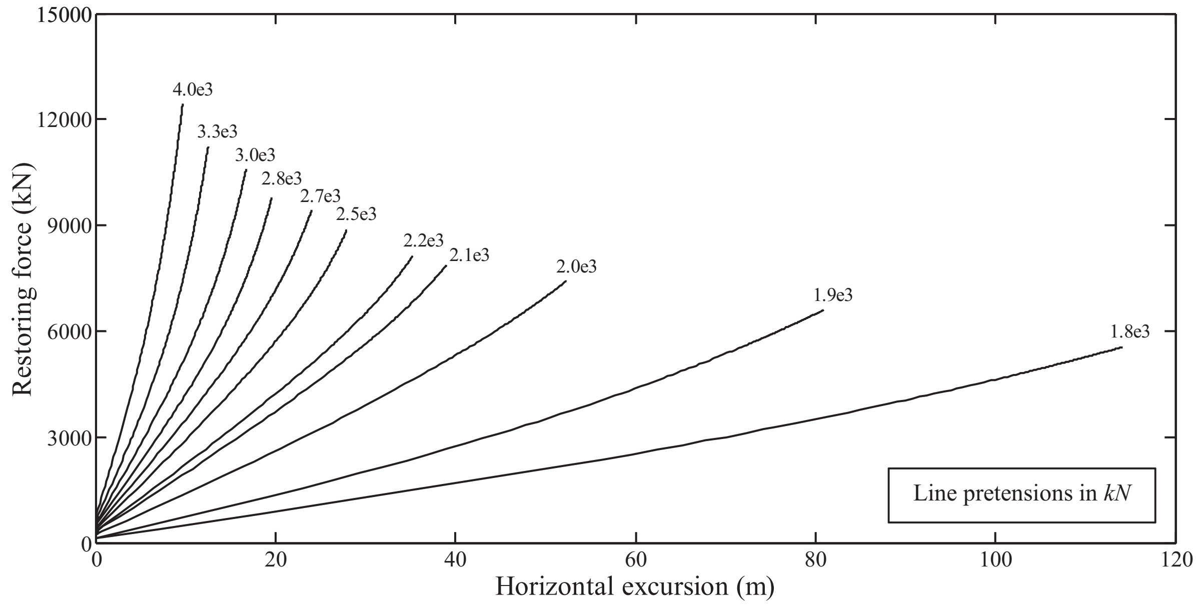

Fig. 5 Variation of the restoring force in configuration-II for different line pretensions

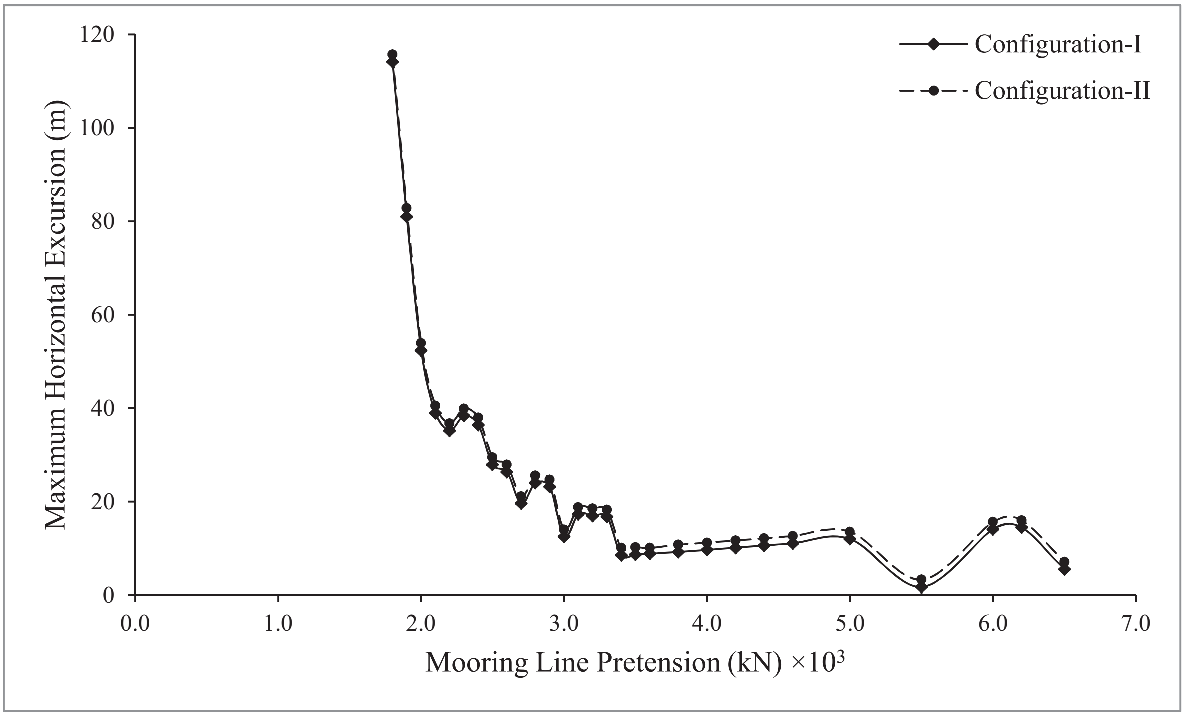

Fig. 6 Maximum permissible horizontal excursions by the mooring system in the wave heading

Conclusions

Based on the numerical study conducted, following conclusions can be drawn:

1. For any mooring line configuration, restoring performance of the mooring system can be enhanced with increase in the line pretensions.
2. The maximum permissible excursion by the mooring system decreases as the line pretension is increased.
3. The reduction in the maximum permissible excursions of the mooring system is significant for relatively lower line pretensions.
4. Though increase in line pretension improves the restoring behaviour of mooring system, decrease in maximum permissible excursions shall be taken into consideration while designing the mooring system of any floating platform.

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