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A Studyon Mooring Systemsof an Offshore Floating Platform for Different Configurations

Anurag Yenduri[1, a], Montasir Osman Ahmed[2, b], V. J. Kurian[3, c]

[1, 2, 3]Dept. of Civil Engineering, Universiti Teknologi PETRONAS, Tronoh, Perak, Malaysia – 31750

[a]yendurianurag@gmail.com, [b]montasir.ahmedali, [c]kurian_john@petronas.com.my

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Abstract. Moored systemsof floating platforms typically have mooring lines in groups,attached to hull of the platform in different configurations.Study on therestoring behaviour of these systemsfor variousparameters of mooring lines gives an insight to decide on the preliminary design of platforms.This paper includesparametric study on the behaviour of mooring systems for various symmetric, asymmetric configurations of the lines. To compute the restoring forces of the mooring system,quasi-static analysis has been adopted and a MATLAB code named *QSAML* has been developed, validated with experimental tests and used for the parametric study.It has been observed that, the restoring capability of mooring system reduces whenthe lines are placed away from the wave heading.For any wave heading, the variation in restoring behaviour of mooring system with symmetric configurations is insignificant up to relatively small excursions of the platform.

Introduction

Mooring systems are widely used in station-keeping of floating systems. In the recent years, the operational scope of the oil companies started shiftingto deep and ultra-deep waters in order to meet the oil demand-supply equity.Hence, the initiative to exploit the reserves in deeper waters has led the researchers to extend the limits of station-keeping systems for the offshore floating platforms.Till date, several mooring systems have been designed for floating platforms. Among the different types present, the spread moorings typically consisting of mooring lines spread around the platformare preferred as they have long service life and can be used for all sizes of the platform at any water depths.

Placement of several mooring lines around the platform provides the principal resistance to displacements in the horizontal plane induced by the environmental loading [7].There is a need to incorporate the dynamic considerations in the analysis/design procedure for the deep-water mooring systems but the Quasi-static approach which has been proven to be a proper design tool for the mooring systems is considered a better choice in the first approach as it is almost certain to achieve convergence and if desired, further analysis may then be carried out using the output of the static analysis as initial conditions for the dynamic analysis [5, 6,7, 8].

This paper involves 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 the parametric study. The motivation for this work lies with investigating the behaviour of mooring systems for various configurations of the lines which can givean insight to the design engineers in selecting mooring line configurations for the platforms.

Governing Equations for the Mooring Line Analysis

The nonlinear relationship between the restoring force and horizontal excursion of a mooring line usually 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, in the line force due to direct fluid loading caused from the waves; (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.

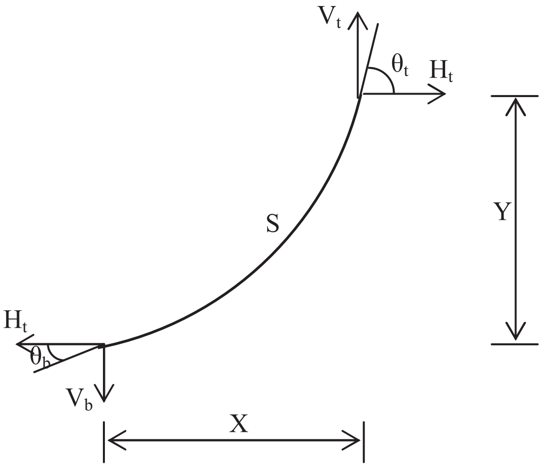

Fig. 1 Free body diagram of a freely suspended mooring line

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

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

The extension of any segment under increased line tension can be evaluated using Eq. 3.

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

where T_0 – Initial line tension when the segment length is S_0, T – Increased average line tension.

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 – Total number of mooring lines; θ_j – Angle between the j^{th} mooring line and the direction of excursion; δ_j – Excursion for the j^{th} mooring line; $H_j(\delta_j)$ – Associated horizontal force with $\delta_j=\delta\cos(\pi-\theta_j)$.

Numerical Modelling of the Mooring Lines

The motions offloating platform depend on the restoring performance of mooring lines attached to it at the hull. Hence, mooring lines configurations greatly affect the design of the platform.Therefore, it is essential to study their effect on the behaviour of mooring systems and opt for the best suitable.

For the parametric study, a floating platform having the fairleads at a height of 941.832m from the sea bed is considered.Various symmetric and asymmetric configurations are studied fortwo mooring line arrangements: 3×3 and 4×4(*Note:* I×J - 'I' denotes number of mooring line groups & 'J' denotes number of lines in each group).These two arrangements are chosen in regards to the present scenario of floating platforms containing mooring lines more commonly in three or four groups with three to four lines in each group.

To ease the analysis procedure, each I^{th}mooring line group is considered as one line representing the total restoring behaviour of 'J' mooring lines in each group as shown in Fig. 2.

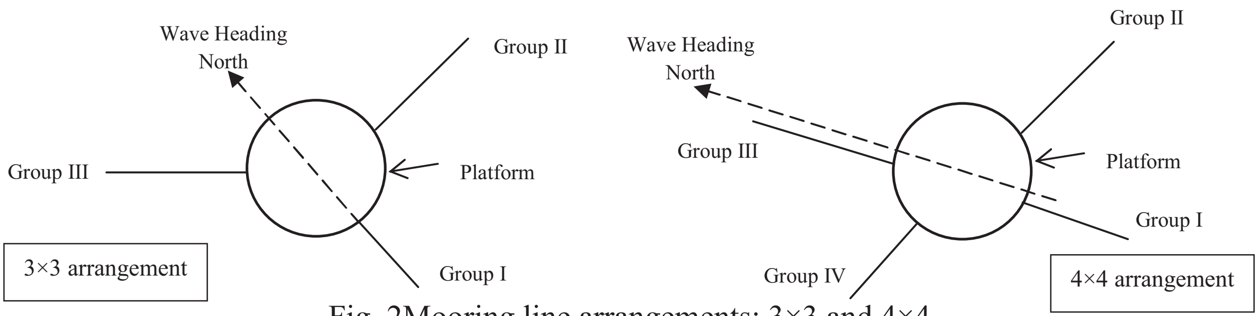

Fig. 2Mooring line arrangements: 3×3 and 4×4

Symmetric. The mooring lines are placed symmetrical to each other and various configurations have been generated by changing the wave headingwith respect to one mooring line, from 0^0 to 60^0 for 3×3 arrangement and 0^0 to 45^0 for 4×4 arrangement, as depicted in Table 1.

Asymmetric. For 3×3 arrangement, these configurations are generated by changing only one mooring line (with other lines retained as in symmetric configurations) with respect to the wave heading from 0^0 to 60^0. Similarly, for 4×4 arrangement these configurations are generated for two cases: (1) Only one mooring line is changed; and (2) Two mooring lines are changed simultaneously; from 0^0 to 45^0 with respect to the wave heading, as depicted in Table 1.

Table 1 Configurations of mooring lines considered for the parametric study
(Azimuth angles are mentioned with respect to *wave heading south*)

Legend	Nomenclature	Mooring Line Arrangement	Mooring Line Configurations	Remarks
Symmetric	Study-1	3×3	a) 0^0, 120^0, 240^0 b) 15^0, 135^0, 255^0 c) 30^0, 150^0, 270^0 d) 45^0, 165^0, 285^0 e) 60^0, 180^0, 300^0	All the three lines are placed at 120^0 to each other
	Study-2	4×4	a) 0^0, 90^0, 180^0, 270^0 b) 15^0, 105^0, 195^0, 285^0 c) 30^0, 120^0, 210^0, 300^0 d) 45^0, 135^0, 225^0, 315^0	All the four lines are placed at 90^0 to each other
Asymmetric	Study-3	3×3	a) 15^0, 120^0, 240^0 b) 30^0, 120^0, 240^0 c) 45^0, 120^0, 240^0 d) 60^0, 120^0, 240^0	–
	Study-4	4×4	a) 15^0, 90^0, 180^0, 270^0 b) 30^0, 90^0, 180^0, 270^0 c) 45^0, 90^0, 180^0, 270^0	Case 1
	Study-5		a) 15^0, 105^0, 180^0, 270^0 b) 30^0, 120^0, 180^0, 270^0 c) 45^0, 135^0, 180^0, 270^0	Case 2

To compute restoring forces in mooring lines, 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 MARLIN truss spar mooring configuration given in Table 3, Fig. 3.

The material properties – wet weight, effective modulus, breaking loads and lengths of the various components of mooring linesused for MARLIN truss spar platform are as given in Table 4.

Table 3 MARLIN truss spar mooringconfiguration
(Azimuth angles are mentioned with respect to *wave heading south*)

Group	Configuration
I	0^0, 5^0, 5^0
II	115^0, 120^0, 125^0
III	235^0, 240^0, 245^0

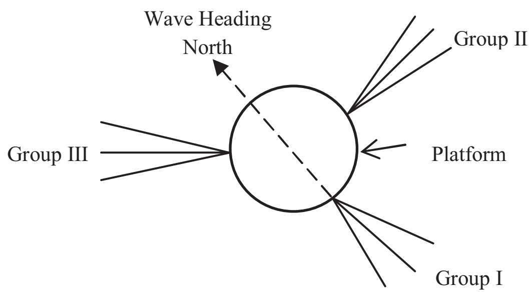

Fig. 3 Mooring arrangement of the platform used for validation

Table 4Characteristics of the MARLIN truss spar mooring lines

Legend	Top Component	Middle Component	Lower Component
Type	Chain cable	Spiral 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 4. 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 [9].

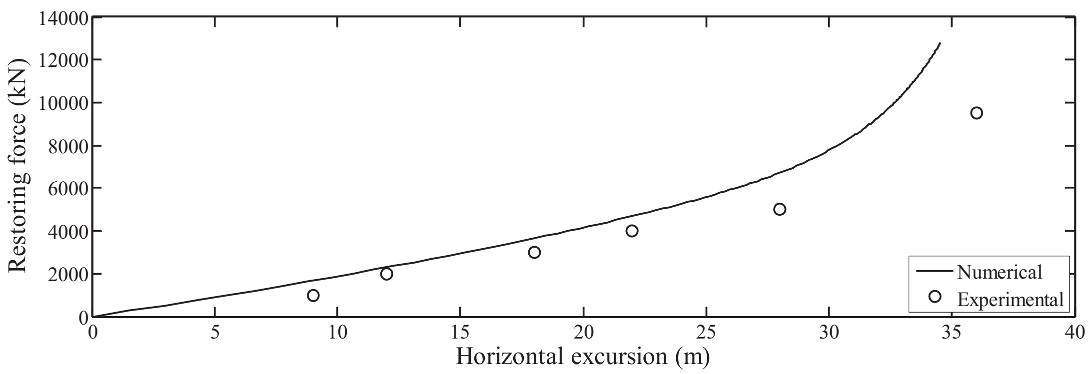

Fig. 4 Validation of numerical predictions with experimental measurements

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.

Symmetric Configurations. The restoring behaviour of mooring system for different configurations is as shown in Figs. 5 and 6. It can be inferred that restoring force of the two mooring line arrangements: 3×3, 4×4 decreases as the lines are shifted away from wave heading.

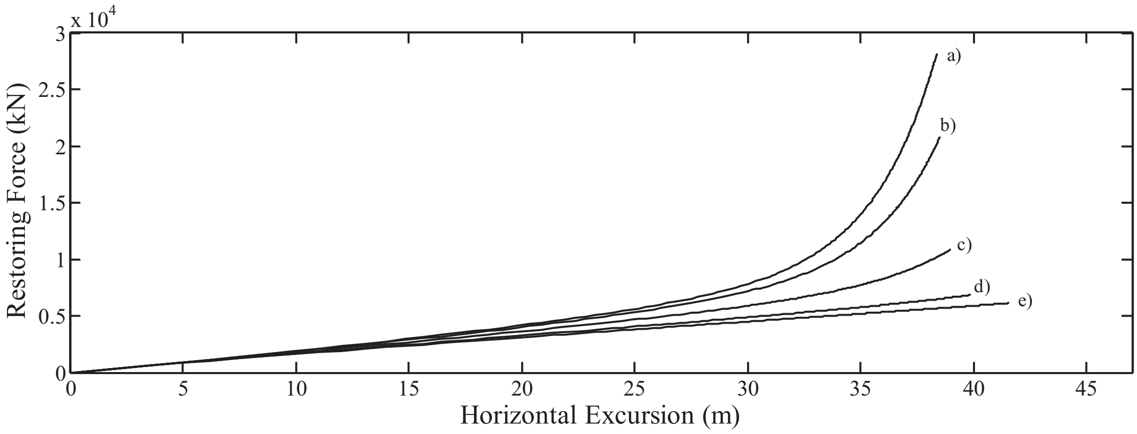

Fig. 5Mooring restoring force in 3×3 arrangement for symmetric configurations (Study-1)

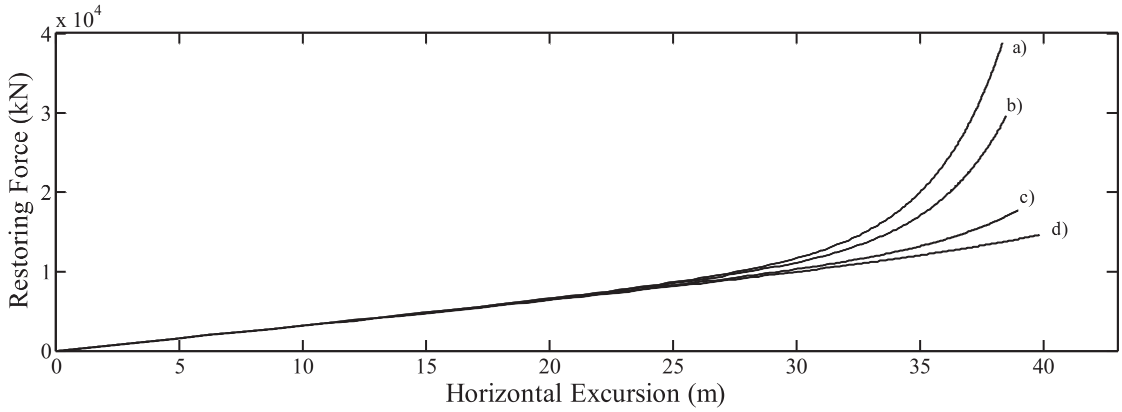

Fig. 5Mooring restoring force in 4×4 arrangement for symmetric configurations (Study-2)

The variation in restoring behaviour of mooring system is found to be insignificant for all the wave headings. For 3×3 arrangement, the restoring behaviour of mooring system does not show significant difference until 20m of excursion and for 4×4 arrangement, until 30m of excursion and thereafter a significant variation is observed.It also implies that as the number of mooring line groups are increased, variation in the restoring behaviour of mooring system remains insignificant up to relatively large excursions of the platform.

Asymmetric Configurations. Similar to the symmetric configurations study; from Figs. 7 and 8, it can be observed that the restoring capability of the mooring system decreases for both the arrangements: 3×3, 4×4 as the lines are placed away from the wave heading.

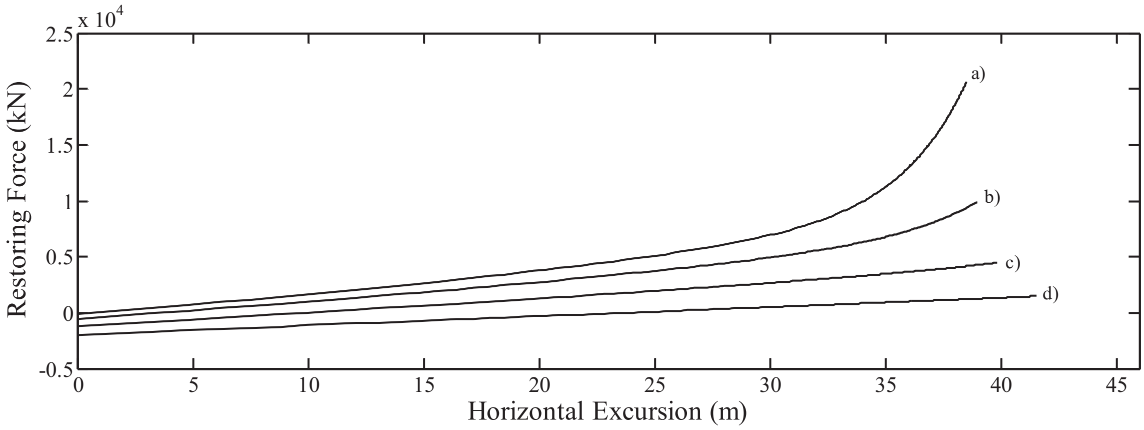

Fig. 7Mooring restoring force in 3×3 arrangement for asymmetric configurations (Study-3)

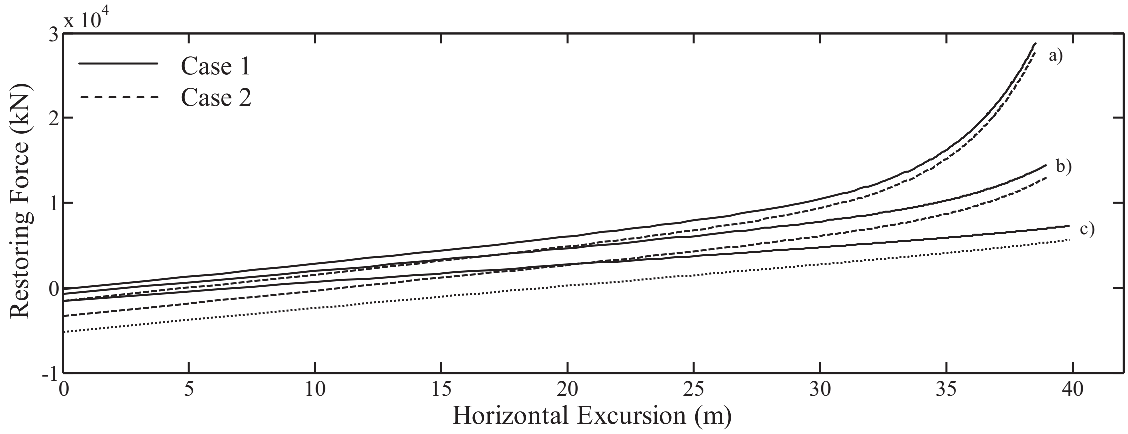

Fig. 8Mooring restoring force in 4×4 arrangement for asymmetric configurations (Study-4, 5)

From Fig. 8,it can be observed that the difference in restoring behaviour between cases: 1 and 2 for line configurations: (a),(b) and (c) is less with difference for(a) being the least.

Conclusions

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

1) In general, the restoring capability of any mooring system with symmetric or asymmetric configuration decreases as the line group is shifted away from wave heading.
2) For relatively small horizontal excursions, mooring systems with symmetric configurations show insignificant difference in their restoring behaviour for any wave heading.
3) In conjunction withconclusion-2; when the number of mooring line groups is increased, the differencecan be insignificant even up to relatively large excursions.
4) Study conducted on asymmetric configurations (for 4×4 mooring arrangement)obtained by varying one and two mooring linesconclude that there is no significant difference betweenrestoring behaviour of the two mooring configurations i.e. respective case: 1 and 2.

References

[1] A. K. Agarwal, A. K. Jain, Dynamic behaviour of offshore spar platforms under regular sea waves, Journal of Ocean Engineering 30 (2003) 487-516.

[2] Jason I. Gobat, Mark A. Grosenbaugh, A simple model for heave-induce dynamic tension in catenary moorings, Journal of Applied Ocean Research 23 (2001) 159-174.

[3] M. B. Rosales, C. P. Filipich, Full modelling of the mooring non-linearity in a two-dimensional floating structure, International Journal of Non-Linear Mechanics 41 (2006) 1-17.

[4] M. J. Downie, J. M. R. Graham, C. Hall, A. Incecik, I. Nygaard, An experimental investigation of motion control devices for truss spars, Journal of Marine Structures 13 (2000) 75-90.

[5] R. Pascoal, S. Huang, N. Barltrop, C. GuedesSoares, Assessment of the effect of mooring systems on the horizontal motions with an equivalent force to model, Journal of Ocean Engineering 33 (2006) 1644-1668.
[6] R. Pascoal, S. Huang, N. Barltrop, C. GuedesSoares, Equivalent force model for the effect of mooring systems on the horizontal motions, Journal of Applied Ocean Research 27 (2005) 165-172.
[7] Russel J. Smith, Colin J. MacFarlane, Statics of a three component mooring line, Journal of Ocean Engineering 28 (2001) 899-914.
[8] S. A. Mavrakos, V. J. Papazoglou, M. S. Trintafyllou, J. Hatjigeorgiou, Deep water mooring dynamics, Journal of Marine Structures 9 (1996) 181-209.
[9] ZhihuangRan, Coupled dynamic analysis of floating structures in waves and currents, Ph.D Thesis, Texas A&M University, Texas, 2000.