Design of Mooring Systems in Extreme Sea States with focus on Viscous Drift Force Modelling

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Problem

In recent years, the requirements to the mooring and station keeping systems of mobile and permanent units have become more complex. For the last decade there have been several unexpected mooring failures caused by unexpected forces that were not accounted for in the design process. In order to increase the capabilities of the oil and gas industry, it is crucial to account for the forces acting on the structures. How to model them correctly and how to predict the maximum tension in the mooring lines in accordance to existing regulations is of specific interest to prevent mooring line failures.

Objective and scope

The overall objective of this master thesis is to increase the knowledge on extreme weather loads and load effects in mooring systems for semi-submersible platforms. Particular focus to be given on the hydrodynamic loading and viscous drift forces in extreme wave conditions. A mooring system is designed and explained as a basis for further analysis. Different numerical simulation methods of the mooring system is compared in order to evaluate their suitability with respect to the most probable maximum tension in a mooring line.

The formula presented below were incorporated in *DNVGL-OS-E301* in July 2018. The formula is of specific interest for the subject as it includes viscous effects and current interaction effects to potential theory [1][2].

The formula for the wave drift force coefficient (wave drift force per unit amplitude squared) in horizontal direction i (x or y) is

$$f_{d,i}(\omega, U_c, H_s) = (1 + C_p U_c \cos\beta_{wc}) \cdot f_{d,i}^{(pot)}(\omega_e) + B(\omega) \cdot (G \cdot U_c \cos\beta_{cw} + H_s) \begin{pmatrix} \cos\beta \\ \sin\beta \end{pmatrix} \quad [\mathrm{kN/m^2}]$$

$$B(\omega) = \tilde{k}(\omega) \cdot d_{sum} \cdot p(\omega) \quad [\mathrm{kN/m^3}]$$

$$p(\omega) = \exp(-0.95(kD_0)^3) \quad [\mathrm{kN/m^3}]$$

$$\tilde{k}(\omega) = \frac{k}{1 + (kL)^{-2}} \quad [\mathrm{m^{-1}}]$$

where

$f_{d,i}^{(pot)}(\omega)$	=	Wave drift coefficients from first-order potential theory	[kN/m²]
A	=	Wave amplitude	[m]
H_s	=	Significant wave height	[m]
U_c	=	Current velocity	[m/s]
ω	=	Angular wave frequency	[rad/s]
ω_e	=	Angular wave frequency of encounter	[rad/s]
β_{cw}	=	$\beta - \alpha$ = angle between wave and current directions	[rad]
k	=	Wave number (ω^2 / g for deep water)	[m⁻¹]
D_0	=	Equivalent diameter = $\sqrt{\frac{4A_{WP}}{N\pi}}$	[m]
A_{WP}	=	Water plane area	[m²]
N	=	Number of columns	-
d_{sum}	=	ND_0	[m]
L	=	total platform dimension (small kL means platform follows the wave orbital motions)	[m]
G	=	10 sec. Viscous wave-current interaction part, found empirically.	[s]
C_p	=	Potential-flow wave-current interaction coefficient, chosen to be 0.25. This part of the formulation is adopted from the simplified formulations like Aranha's formula (1996). The value 0.25 is a typical value of $4\omega/g$ obtained for a wave period 10 sec.	[s/m]

$\cos\beta$ for i = x-direction; $\sin\beta$ for i = y-direction

References

[1] DNVGL - *Handbook on low-frequency wave forces and response - guidelines and recommendations*, Confidential (2017)

[2] DNVGL - *Position mooring*, DNVGL-OS-E301 (2018)

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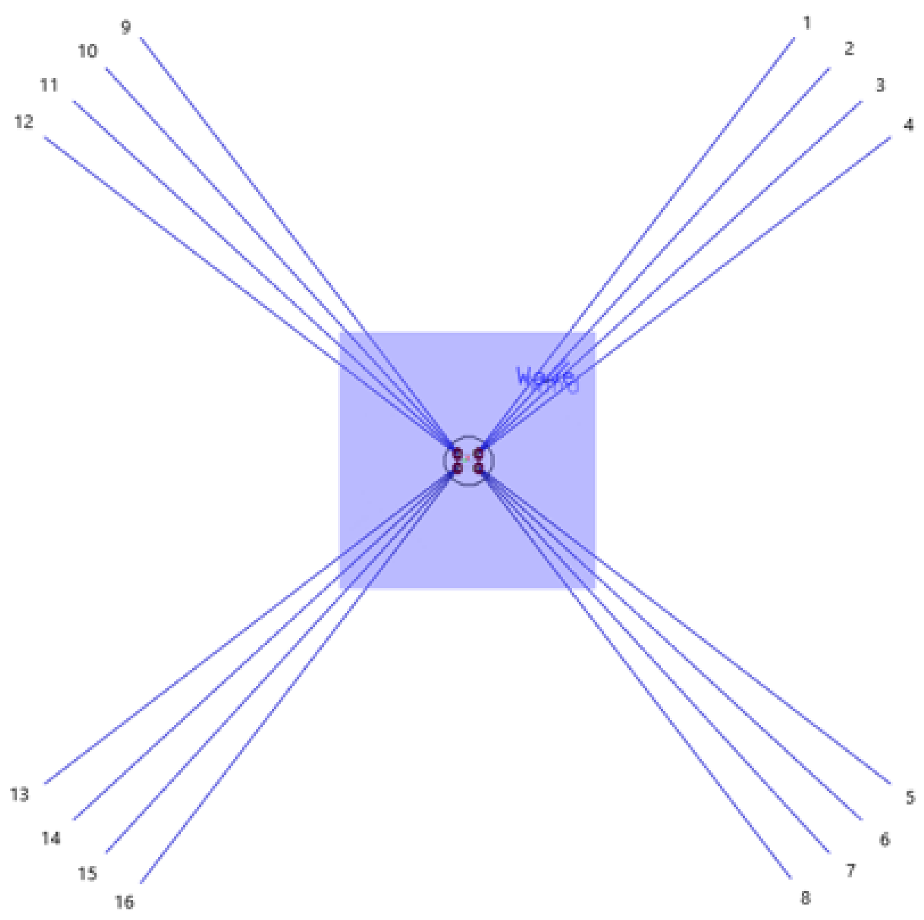
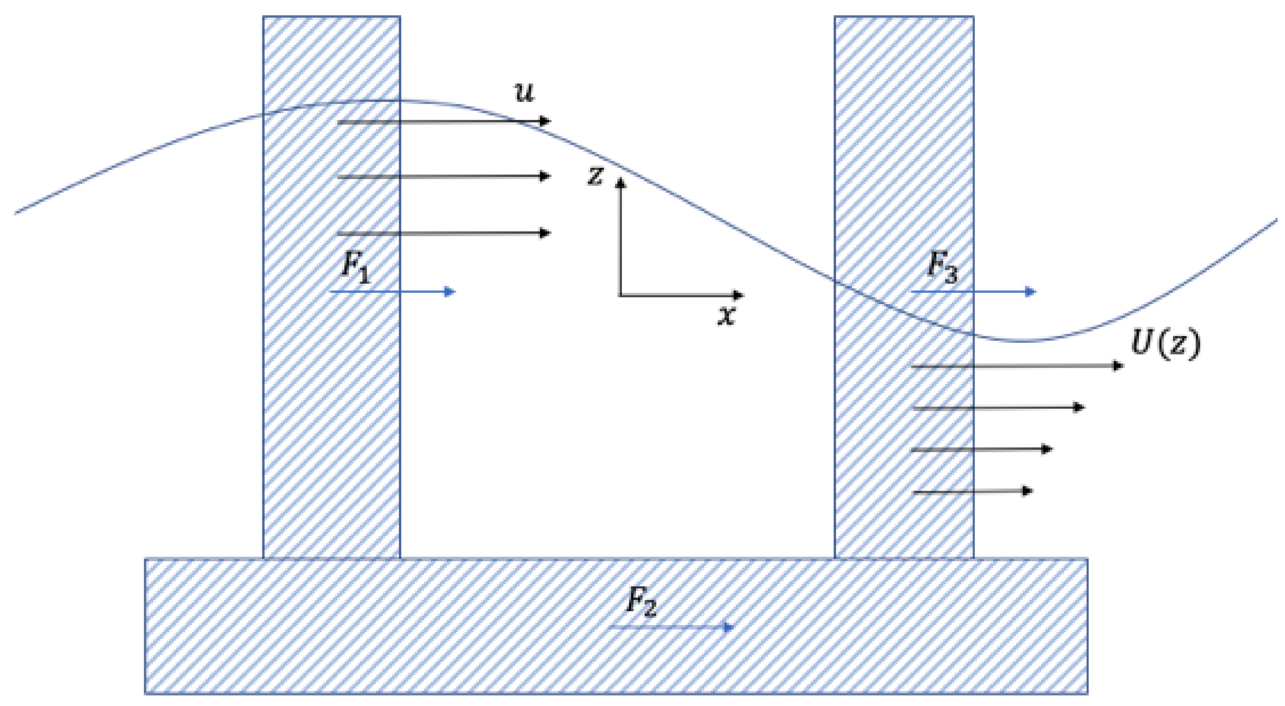
Viscous drift force modelling

One of the main design parameters for mooring system design is the most probable maximum tension, T_{MPM}, in the most heavily loaded mooring line. This thesis focuses on two ways to calculate T_{MPM}. Either by calculation of the forces from potential wave drift coefficients in combination with wave and current coefficients, or by slender modelling as formula one below illustrates. Slender modelling differentiates from potential drift force modelling by introducing slender elements to account for the viscous forces to the actual wave surface. This gives second order waves with integration of wave forces to wave surface. In addition, slender modelling includes contributions from the mean wave velocity, current velocity and both LF and WF velocities of the semi-submersible. The WF contribution is found in the local CoG for each slender element whilst the others are related directly to the global CoG.



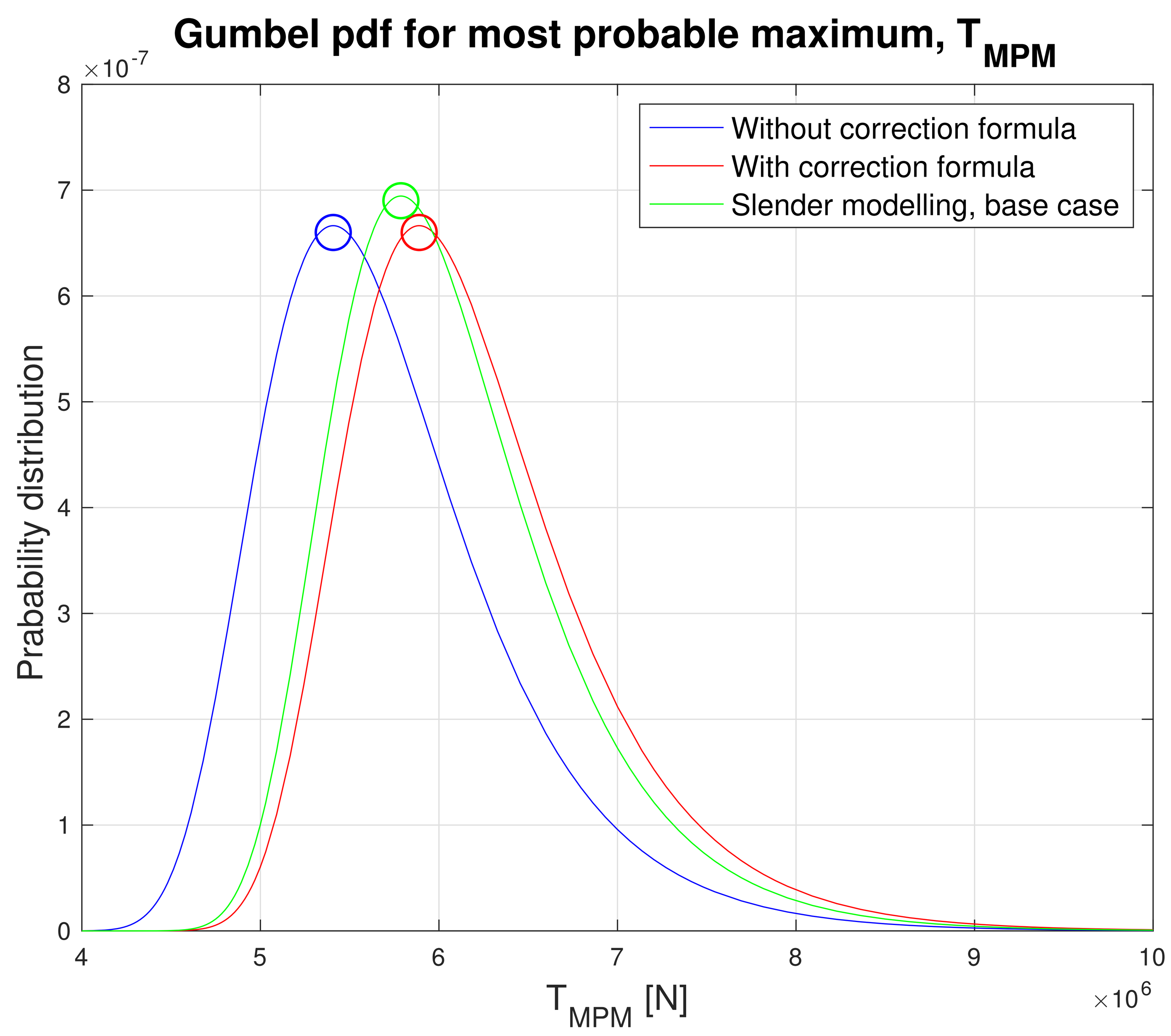


$$F_{Di} = \int_z \frac{1}{2}\rho C_D(z) D dz (\bar{u} + U(z)) - (\dot{x}_{LF} + \dot{x}_{WF}^{loc})((\bar{u} + U(z)) - (\dot{x}_{LF} + \dot{x}_{WF}^{loc})) \quad (1)$$

$$F_{Dtot} = \sum_{i=1}^{N} F_{Di} \quad (2)$$

Results and conclusion

First, the results with corrected wave drift coefficients compared to the "old" method for calculation of the most probable maximum tension shows an increase in T_{MPM} of 8.9%.



When the results obtained by utilizing the correction formula is compared to results obtained by slender modelling, it may seem that the correction formula over predicts the most probable maximum tension. The difference in percentage between the two methods is 1.7%. The slender modelling results are dependent on the elected drag coefficients for the slender elements and these are not necessary fixed at one value. Subsequently, a sensitivity analysis of the effect from the drag coefficients on T_{MPM} has been performed.