Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

Dynamic seabed-anchor capacity enhancements for taut-moored floating offshore wind

Katherine Kwa[1,*], David White[1], Oscar Festa[1] and Susan Gourvenec[1]

[1] University of Southampton
* Corresponding author: k.a.kwa@soton.ac.uk

Decarbonisation of global energy supply to meet Net Zero targets by 2050 requires rapid expansion of offshore wind [4]. Much of this growth will come from floating offshore wind (FOW) technology where seabeds are less congested, high energy wind resources are located and conventional fixed offshore wind is not practical [1]. The required scale of FOW requires a step change in mooring and anchoring technology compared to existing hydrocarbon solutions. New, efficient and reliable mooring and anchoring systems are essential to economically deliver the necessary FOW [1]. Taut mooring arrangements can be attractive for FOW turbines as they require less length and lighter synthetic mooring line than traditional chain catenary mooring arrangements. However, taut moorings transmit significantly higher mean and peak tensions to the anchor compared to catenary moorings. It is therefore important to fully quantify the capacity available from anchors during typical FOW load conditions, including dynamic effects.

This study focuses on how a numerical anchor macro model, *Ancmac* [6], can be used to capture and quantify dynamic anchor-seabed capacity benefits such as from seabed added mass, F_{am} [5] and viscous soil strength effects. These effects can enhance the dynamic anchor capacity and are not typically considered in anchor design. Typical mooring-floater fluid-structure interaction analyses also model the connection of the mooring lines to the seabed as a fixed pin connection and so seabed-anchor-mooring interactions are not typically considered. *Ancmac* can replace this fixed pin connection node at the seabed as it uses mechanical analogue components (e.g. spring-viscous-slider and mass) to simply and practically link forces on the anchor with anchor and chain movements in the time domain to determine the seabed response and the current available anchor capacity. This study presents an example case where *Ancmac* is used to model the response of an embedded plate anchor that is subjected to a high amplitude, short period (T= 6 and 10 s) high mean load event (Figure 1a). The anchor loads , F_m, are derived from applying a 1-50 year storm design loading event on a 15MW FOW turbine [3] with a taut mooring line configuration composed of high modulus synthetic polyester rope [8].

Results show that if dynamic seabed benefits are not considered (purple line in Figure 1a), then a static anchor capacity of $Q_{ult,stat}$= 4.15 MN and corresponding anchor size of $A_{p,stat}$= 11.13 m^2 is required (for an anchor buried in slightly overconsolidated soft clay s_u=30 kPa and bearing capacity factor N_c=12.42). If beneficial dynamic seabed enhancements are considered (shown by red lines $F_g = f(v)$), then a lower initial static anchor capacity can be adopted Q_0=3.13 MN, which corresponds to a ~25% decrease in the required anchor size ($A_{p,dyn}$=8.41 m^2). During the design loading event, as the applied anchor load, F_m increases above the available static capacity, towards the maximum applied value, the anchor begins to move (Figure 1b) generating dynamic resistance from mobilising the non-linear viscous slider and added mass resistance components. The resistance in the viscous slider component is based on a model for the change in undrained strength with increasing equivalent strain rate (γ'=v/D, where D is anchor diameter), as shown in Figure 1c. The resistance from the viscous slider component reaches a maximum at the time marked V slightly after the peak of the applied mooring line loads, at time M, as shown in Figure 1a-c. Reducing the period of the applied load (T=10 s to 6 s) increased the added mass resistance as the anchor is subjected to higher accelerations. As a result, the anchor experienced significantly smaller (~50% less) maximum displacement and reduced velocities. This comparison is also evident in Figure 1d, which compares the contributions of resistance forces from the spring-viscous-slider and added mass components.

DOI: https://doi.org/10.59490/seg23.2023.619

Ancmac can also capture the long-term enhancements in seabed strength and anchor capacity as a time-varying function of the life-cycle of seasonally varying, operational applied loads. This could, for example, further reduce the required anchor sizes, as s_u can increase from beneficial long-term seabed consolidation effects [7]-[10]. These short and long-term seabed benefits that occur over the range of different loading timescales, and result in enhanced anchor capacities for loads that are relevant to FOW taut mooring configurations, will be further discussed during the presentation.

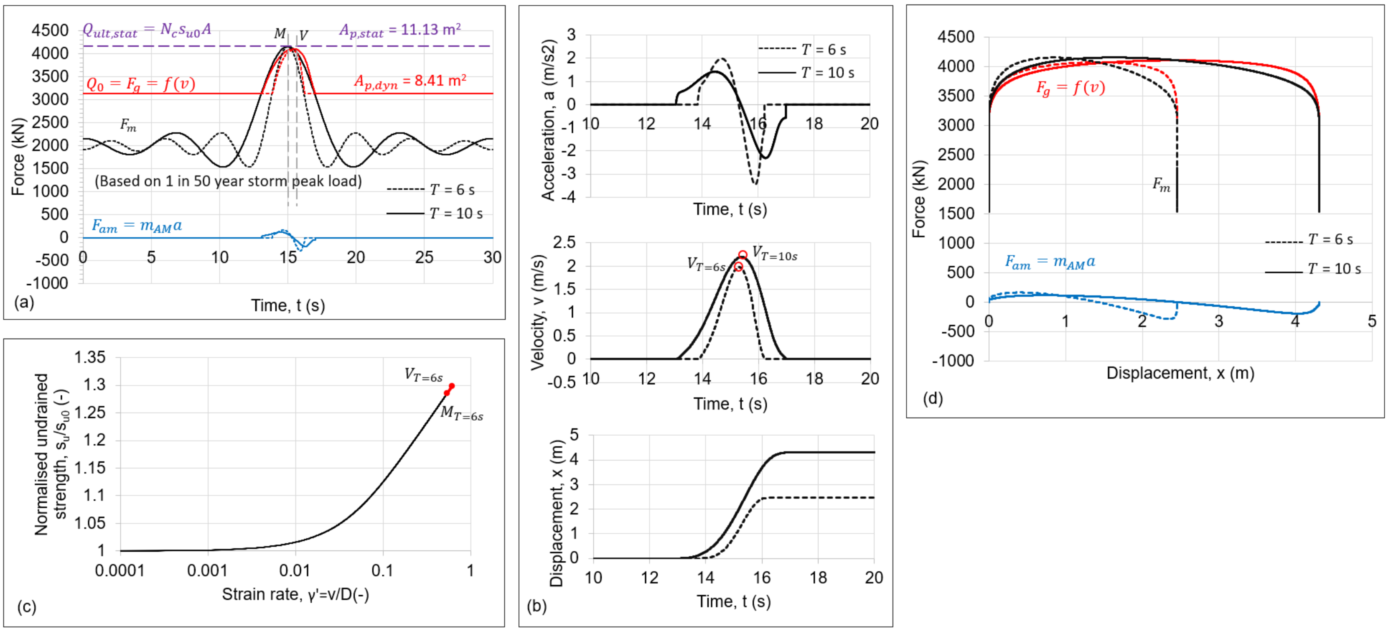

Figure 1: Summary results showing capacity enhancement during dynamic loading using numerical anchor macro model *Ancmac*

Contributor statement: Katherine Kwa: Conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, writing- original draft, writing- review & editing; David White: Conceptualisation, funding acquisition, writing- review & editing; Oscar Festa: analysis, writing -review & editing; Susan Gourvenec: Conceptualisation, funding acquisition, writing- review & editing.

Acknowledgments

This work forms part of research supported by the Royal Academy of Engineering under the Research Fellowship Programme, RAEng Chair in Emerging Technologes Centre of Excellence in Intelligent & Resilient Ocean Engineering (IROE), and Supergen ORE Hub (Grant EPSRC EP/S000747/1). Katherine Kwa is supported by the RAEng Research Fellowship Scheme, David White is supported by the Supergen ORE Hub and Susan Gourvenec is supported by the Royal Academy of Engineering through the Chair in Emerging Technologies scheme.

References

[1] Cerfontaine, B., White, D., Kwa, K., Gourvenec, S., Knappett, J., & Brown, M. (2023). Anchor geotechnics for floating offshore wind: Current technologies and future innovations. Ocean Engineering, 279, 114327. https://doi.org/10.1016/j.oceaneng.2023.114327

[2] Euro. Tech. & Innov. Platform on Wind Energy (2020) ETIP Wind Roadmap. https://etipwind.eu/files/r ports/ETIPWind-roadmap-2020.pdf

[3] Allen, Viscelli, Dagher, Goupee, Evan, Abbas, Hall, Barter, (2020) Definition of the UMaine VolturnUS-S Reference Platform Developed for the IEA Wind 15-Megawatt Offshore Reference Wind Turbine. Golden, CO: NREL NREL/TP-5000-76773.

[4] GWEC (2022) Global Offshore Wind Report, GWEC, https://gwec.net/gwecs-global-offshore-wind-report/

[5] Kwa, K.A., Weymouth, G.D., White, D.J. & Martin (2021). Analysis of the added mass term in soil bearing capacity problems, Geotechnique Letters (11) 80-87 https://doi.org/10.1680/jgele.20.00097

[6] Kwa, K. A., Sivasithamparam, N., Deeks, A., & White, D. J. (2022). A numerical macro model to simulate the whole life response of anchors for floating offshore renewable energy systems. In Int. Conf. on Off. Mech. & Arctic Eng. (Vol. 85949, p. V009T10A003). ASME.

[7] Kwa, K. A., & White, D. J. (2023). Numerical modelling of plate anchors under sustained load: the enhancement of capacity from consolidation. Computers and Geotechnics, 158, 105367. https://doi.org/10.1016/j.compgeo.2023.105367

[8] Kwa.K.A., Festa, O., White, D., Sobey, A. & Gourvenec, S. (2023) Integrated numerical modelling of soil-anchor-mooring line- floater response for floating offshore wind, Int. Conf. on Numerical Methods in Geomechanics (NUMGE) 2023, London

[9] Kwa, K.A., Tosdevin, T. Jin, S. White, D.J. & Greaves, D. (2023) Whole-life modelling of anchor capacity for floating systems: the RSN-CSI approach (In review).

[10] Laham, N. I., Kwa, K. A., White, D. J., & Gourvenec, S. M. (2021). Episodic simple shear tests to measure strength changes for whole-life geotechnical design. Géotechnique Letters, 11(1), 103-111. https://doi.org/10.1680/jgele.20.00124