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Title: Numerical modelling of monopiles for offshore wind farms

Abstract

Offshore wind, a renewable source of energy, is expected to satisfy about 25% of the UK electricity demand by 2025. Since offshore wind turbine foundations, of which monopiles are the most popular, constitute a large proportion of the construction cost of an offshore wind farm, it is essential to design them efficiently.

Monopiles are large diameter piles subjected to cyclic lateral loads from wind and waves. They are currently designed using the *p-y* method, which was developed for small diameter piles for offshore oil and gas installations. Current research on monopiles has been focussed on sandy soils that dominate the continental shelf of countries in mainland Europe, such as Germany. However, geotechnical investigations for UK offshore wind farms indicate an appreciable presence of clays and layered soils, in which monopile response is not well-understood.

Using three-dimensional finite element analysis that was validated against centrifuge test data, the deformation mechanism of monopiles and small diameter piles in clays was found to be distinctly different. Axial and lateral response of monopiles was also examined through which it was established that the *p-y* method was overly conservative for designing monopiles in soft clay.

Analysis in layered soil profiles indicated that a deep-lying thin layer of soft clay between competent soil strata caused a significant reduction in soil resistance against the monopile. Conversely, due to the monopile deforming as a rigid body, the effect of superficial layers of soft clay and loose sand was insignificant. In comparison, the equivalent depth *p-y* method was incapable of replicating the continuity between soil layers and as a result grossly over-estimated the monopile lateral capacity.

Simulations investigating cyclic lateral loading of a monopile in stiff London Clay showed that, over 25 cycles, one-way loads induced greater cumulative pile deformation relative to two-way loads. For all load configurations, the progressive accumulation of lateral pile displacement and rotation at mudline, at a rate that reduced with each cycle, was indicative of clay hardening.

Favourable interaction was obtained between the monopile, hybrid structural features and rock armour leading to an improvement in the lateral pile capacity in stiff clay. Although the skirted steel footing brought about the largest increase in monopile capacity, the steel fins represented better value on account of their lower cost.

Through a comprehensive evaluation of curve fitting techniques for deriving *p-y* curves from discrete bending moment data, the cubic and cubic B-spline methods were found to be consistently accurate for both small and large diameter piles.