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# Input of fully 3D FE soil-structure modelling to the operational analysis of jack-up structures

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ABSTRACT

Jack-ups are mobile structures widely employed in the offshore industry as drilling rigs or installation/maintenance vessels (e.g. for offshore wind farms). To assure safety at each location, *site-specific assessment* is required to predict the performance of the unit during installation and operations. The response of jack-ups to environmental loads is highly affected by the interaction between all footings (*spudcans*) and the underlying soil, an interaction still challenging to describe under general 3D loading.

This work emphasises the potential of 3D continuum simulations to capture non-linear soil-structural interaction in jack-up units. An integrated jack-up–spudcans-soil 3D finite element (FE) model is set up by including strain-hardening soil plasticity and geometrical non-linearity ($P-\Delta$ effects). After preliminary calibration of soil parameters, the FE model is successfully validated against literature results, namely obtained through (i) small-scale centrifuge experiments and (ii) numerical simulations based on macroelement foundation modelling. The validated FE model is then used to inspect several implications of soil modelling assumptions, as well as the response of the jack-up to relevant 3D loading combinations.

The results presented support 3D continuum modelling as a suitable approach to analyse spudcan fixity and, overall, the operational performance of jack-ups. Despite higher conceptual/computational difficulties, fully 3D simulations can valuably complement the insight from (rare) integrated physical modelling, and contribute to the improvement of soil-spudcan macroelement models.

## 1. Introduction

Jack-up structures play a prominent role in oil and gas developments as mobile offshore drilling units (MODUs) in shallow to moderate water depths. They are self-elevating structures, most usually comprising a triangular hull supported by three retractable lattice-work legs (Fig. 1a). The primary advantage of the jack-up design is that it offers a steady and relatively motion-free platform in the drilling position, and mobilises quite quickly and easily. The use of jack-ups is not only limited to drilling operations as they can also serve diverse offshore construction/maintenance works, e.g. for offshore wind farms. When deployed as installation vessels, jack-ups usually come in smaller size and slightly different setups, possibly featuring more than three legs (Fig. 1b).[1]

Jack-ups are slender, dynamic-sensitive structures, whose global compliance under environmental loading is highly influenced by

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[1] The pictures in Fig. 1a and b are courtesy of GustoMSC (Schiedam, Netherlands).

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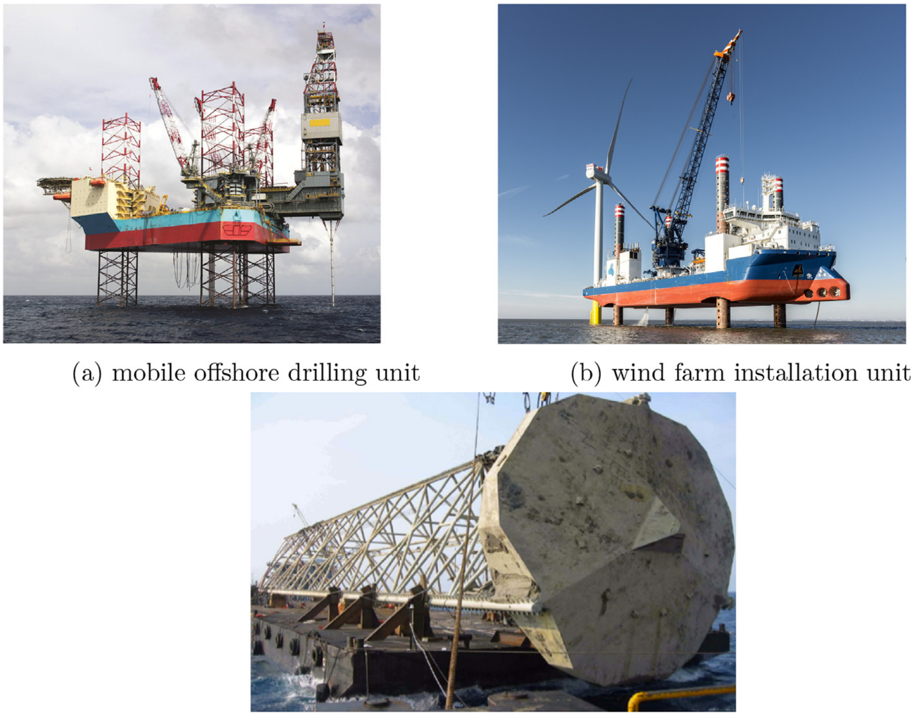

(a) mobile offshore drilling unit (b) wind farm installation unit

(c) spudcan

**Fig. 1.** Jack-up units in offshore developments.

the interaction between the legs and the underlying soil. The jack-up legs are usually endowed with so-called *spudcan* footings (Fig. 1c),[2] saucer-shaped polygonal or quasi-circular foundations with a central spigot and shallowly sloping conical underside [1]. Being jack-ups by definition mobile units, a *site-specific assessment* is required for each new location to guarantee safe installation and operation. In the last decades, industry-academia partnerships have been promoted to develop reliable guidelines for site-specific assessment, including research programmes on geotechnical issues – e.g. the InSafe JIP [2]. The valuable knowledge generated in this area is collected, and continually updated, within the ISO 19905-1 document [3,4], originated from the previous SNAME 5-5A guidelines [5,6].

The ISO standard comprises three acceptance check levels in order of increasing complexity and reduced conservatism: a higher level of check is associated with more sophisticated foundation modelling, and advocated when lower acceptance criteria are not fulfilled. At the highest level – the so-called *Displacement Check* – the ISO standard requires finite element (FE) jack-up analyses including soil non-linearities and large deformation effects, so as to capture the consequences of foundation displacements through integrated soil-structure simulations [4,7]. As noted by Houlsby [8], "*the important interaction at this stage is with structural engineers, who need to be able to analyse the forces in the structure, and for rather flexible structures such as jack-up units the structural forces depend critically on the foundation response*".

This work highlights the relevance of integrated 3D FE soil-foundation-structure modelling to the ISO Displacement Check (Level 3), with focus on the continuum simulation of non-linear soil-spudcan interaction. The ultimate goal is to strengthen the connection between lumped and fully 3D modelling of soil-spudcan interaction, so as to remedy the common dearth of specific field measurements and/or laboratory test results. However, the fully 3D soil–jack-up model has been developed in this spirit without attempting an "omni-comprehensive" modelling of all geotechnical factors, such as the influence of cyclic loading conditions [9] and partial pore water drainage [10].

## 2. Modelling of spudcan fixity in jack-up structural analyses

Due to structural redundancy there is in jack-ups tight interaction between foundation response and structural demand, especially under extreme loading conditions. A typical issue in this context is the evaluation of the moment-rotation response at each spudcan, commonly referred to as *spudcan fixity*. To perform sound structural analyses, engineers must decide whether leg-seabed connections can be treated as pinned, fixed or deformable rotational constraints [8]. The last, most realistic case is in fact quite hard to handle, as the overall spudcan-soil stiffness evolves during operations depending on multiple factors (e.g. soil type/behaviour, spudcan

[2] Picture from http://www.emi.uwa.edu.au/news/uwa-team-investigate-new-footings-mobile-drilling-rigs-0.