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Geotechnical challenge of offshore mudmat foundation stability: Combining analytical and finite element investigation of bearing capacity of sand overlying soft clay

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HIGHLIGHTS

- The challenge of offshore mudmat design under complex soil conditions is showed.
- FE modelling strategies for taking on the mudmat design challenge are illustrated.
- Application of FE modelling to achieving the rational mudmat design is presented.
- The failure mechanism of the soils under complex mudmat loadings is revealed.
- The target penetration depth of the mudmat skirt achievable is demonstrated.

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ABSTRACT

This paper presents how mudmat design of an offshore jacket at North Sea has taken on geotechnical challenge, where very soft clays underlying sand immediately underneath the mudmat prevents the design from directly using conventional analytical procedure. Soil conditions at the jacket site are briefly described and discussed. The paper presents FE modelling strategies adopted for taking on the geotechnical challenge and investigating the bearing capacity of the mudmat under such layered soils; it reveals the failure mechanism of the soils underneath the mudmats during loadings. The paper shows how the FE modelling, together with conventional analytical procedure, has led to the rational development of the bearing capacity envelope and facilitated finalising the design of the mudmats. The paper also briefly presents the skirt penetration analysis to demonstrate the target skirt penetration depth achievable. It has showcased how the geotechnical challenge has been met with the right strategies and holistic approaches. The practical design presented can serve as a reference case for determining the bearing capacity envelope and helping design mudmats, challenged by similar soil condition and mudmat/skirt make-up, for future offshore projects.

1. Introduction

Offshore projects are by nature capital-intensive and a thorough analysis leading to a sound design is a mandate. Pile supported jackets are among major offshore structures and designed to be self supporting during pile driving and installation period by means of mudmats foundations, which act as temporary support during the jacket installation by transferring the temporary loads to the seafloor soils before completion of pile driving and grouting operations. Offshore mudmats are usually made of stiffened steel plates, located adjacent to the jacket leg connections at the mudline level and often fabricated near the bottom

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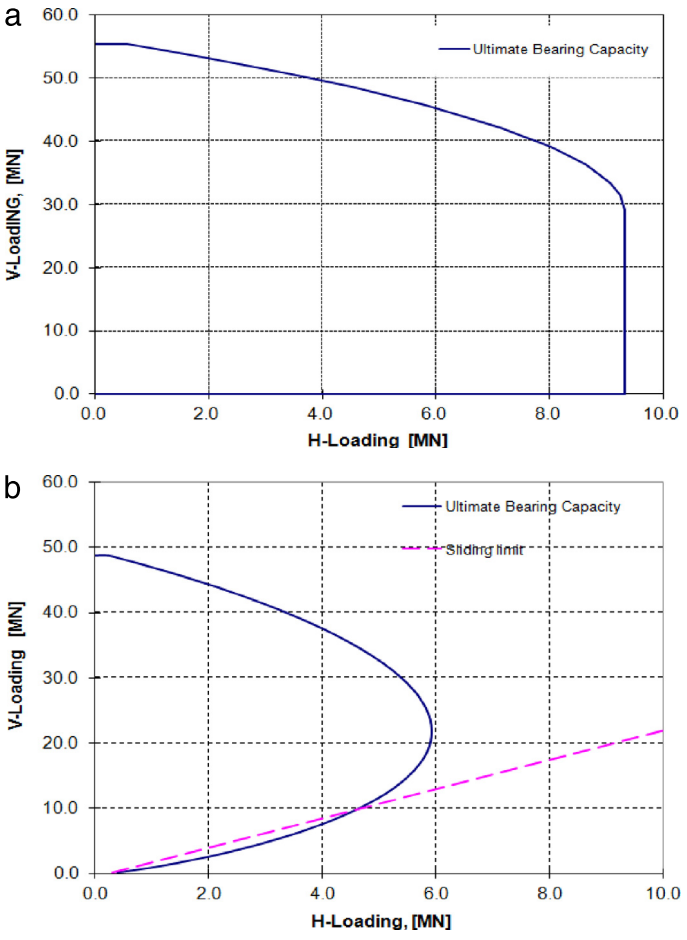

Fig. 1. Illustration of mudmat bearing capacity graphs (V–H Envelope). (a) for clays, (b) for sands.

horizontal brace level of the jacket. The mudmat is often equipped with skirts that penetrate the seabed to increase the capacity against sliding. Fundamentally for an offshore jacket, the skirted mudmat needs to be designed to have adequate stability against vertical and lateral load reactions from a combination of dead load, variable live load, environmental load such as wind, wave and current etc., and to penetrate to the designed depth below seafloor.

The design of mudmat foundations supporting offshore jackets under idealised shallow soil conditions, such as sand or clay only, can be performed in accordance with DNV/ISO procedures.[1–3] Such conventional procedure mainly involves: (i) calculating the load reactions by analysing mudmat stability cases under loading combinations of dead, live and environmental loads; (ii) sizing the mudmat and developing a relevant bearing capacity envelope (or V–H diagram) for either undrained or drained soil conditions (Fig. 1); and (iii) plotting the calculated load reactions onto the developed V–H diagram to check if the load reactions would fall inside the bearing capacity envelope. The above steps may well be required to repeat by trial-and-error to achieve a satisfactory mudmat design. Load and resistance factors are often required to apply the design, depending on the design requirement.

For the layering soil formations such as sound sand overlying very soft clay as presented in X-jacket site considered in this paper, direct use of the above-described procedure will not lead to satisfactory design. Without rationally considering the strength properties of the layering soils underneath the mudmat, the designed mudmat capacity would be potentially inadequate due to soil bearing capacity failure caused by overestimate if it is assumed that the soils consist of sound sand; this will impose unaccepted risks to the jacket installation. On the other hand the mudmat capacity would be underestimated if it is assumed that the soils entirely consist of soft clays, leading to an onerous design and unachievable mudmat skirt penetration. The complexity of the layering soil formations with very soft clays at the X-jacket site has become a significant geotechnical challenge to the mudmat design for the project. To properly take on the geotechnical challenge, the strength properties of the layering soils underneath the mudmat have to be rationally considered in the design. Numerical analyses have been often used to take on challenges similar to that with the X-jacket site.[4–6] The FE modelling has been combined with the conventional analytical procedure to meet the geotechnical challenge presented and to lead to a robust mudmat design for the offshore project.

There are four support legs for the X-jacket, two are 5-pile legs and other two are 4-pile ones; each leg has one

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