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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Offshore projects are by nature capital-intensive and a thorough analysis leading to a sound design is always a requirement. Pile supported jackets are among major offshore structures and designed to be self supporting during pile driving and installation period. An offshore jacket has a mudmat foundation or mudmat, which transfers the temporary loads to the seafloor soils before completion of pile driving operation and acts as a temporary support during the jacket installation. Mudmats are usually made of stiffened steel plates, fabricated at the bottom of the jacket and generally located adjacent to the jacket leg at the mudline level. Each 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.

The subject of this paper - the GK jacket is to be located in the North Sea. The shallow soil conditions at the GK jacket site govern the mudmat design and are of a complex soil layering; immediately below the top 1m sand layer are very soft to soft clays gradually increasing in strength with depth below seabed. This imposes a big geotechnical challenge for the design of the GK jacket mudmats.

The design of mudmat foundations under idealized shallow soil conditions, such as uniformed sand or clay, can be performed in accordance with DNV/ISO procedures based on general bearing capacity (for example Brinch Hansen) formula (Ref. 1 & Ref. 2). This mainly involves:

1) calculating the load reactions by analysing load cases of mudmat stability under variable loading combinations of dead, live and environmental loads;
2) sizing the mudmat and developing a relevant bearing capacity envelope (or V-H diagram) for either undrained or drained soil conditions; and
3) plotting the calculated load reactions onto the developed V-H diagram to check if the load reactions fall inside the bearing capacity envelope.

The above three steps are often interdependent and require to be repeated by trial-and-error to achieve a satisfactory design. In developing bearing capacity envelope (see Figure enclosed), appropriate load and resistance factors need to be taken into consideration too, depending on the design requirement (Ref. 3 and Ref. 4). To increase the capacity of a mudmat against sliding, the mudmat is often equipped with skirts, which is the case for the mudmats for the GK jacket.

For a complex soil setting up such as at the GK site where sand overlying soft clay, consideration has to be made for soil layering behaviour to achieve a satisfactory design (Ref. 5 and Ref. 6). If assuming that the soils at GK site should entirely consist of soft clays it would underestimate the mudmat capacity, leading to an rather onerous design; or it would overestimate the mudmat capacity and impose significant risk to the jacket installation, if entirely assuming the soils as sand. That means the routine mudmat design procedure, often appropriate for using under an idealised condition of uniform soil type, is not appropriate for the GK site, since it is impossible to reflect the mudmat stability behaviour of layering soils realistically. To meet such geotechnical challenge for the design of the mudmats at the GK site, advanced finite element (FE) analysis technique has therefore been used to facilitate the design.

In the paper, soil formations and soil conditions at the GK jacket site, as revealed by the site geotechnical investigations were briefly described and discussed with its low, representative and high strength profiles. The challenge imposed by layering soils as to how soft clays underlying sand in the shallow part was discussed. The impacts of the challenge on the mudmat design at the GK site was highlighted mainly as two aspects: one is bearing capacity failure due to inadequate mudmat capacity caused by not appropriately representing the soft clays underlying the sand and another is failure for skirt penetrating to penetrate to the target depth due to high soil resistance of the sand.

This paper presents the FE modelling strategies adopted. The 2-D Plaxis FE package was used to investigate the bearing capacity of the mudmat. The paper describes the geometry of the mudmat and its skirts for the Gk jacket, and the FE modelling boundary conditions, then the idealised FE model corresponding to the layered soil profiles and the input soil parameters. The anisotropic features of the soils and the stiffness parameter used are also considered.

The FE modelling of the mudmats at the GK jacket involved using both options of “Prescribed Loads” and “Prescribed Displacement” in Plaxis. For the cases of combining vertical and horizontal loadings, the option of “Prescribed Load” was used, accounting for the major part of the FE modelling. In the modelling with the “Prescribed Load” option, a prescribed vertical loading was assigned, and the mudmat was increasingly loaded by incremental horizontal loading. The modelling process continued until a failure mechanism had developed in the soils. The horizontal loading (Pxi) leading to the development of the failure mechanism and the prescribed vertical loading (Pyi) defines a point (Pxi, Pyi) for deriving a bearing capacity envelope under such a particular combination of the vertical/horizontal loadings. The process was repeated for various combinations of vertical and horizontal loadings and led to defining points of delineating the bearing capacity envelope. The “Prescribed Displacement” option was applied to either pure vertical or pure horizontal loading case. In the modelling with the “Prescribed Displacement” option, the mudmat was increasingly loaded vertically (or horizontally) until the incremental vertical (or horizontal) displacements did not give any further change in vertical (or horizontal) force and a failure mechanism had developed in the soils. This defines the limit for deriving either vertical or sliding capacity of the mudmat.

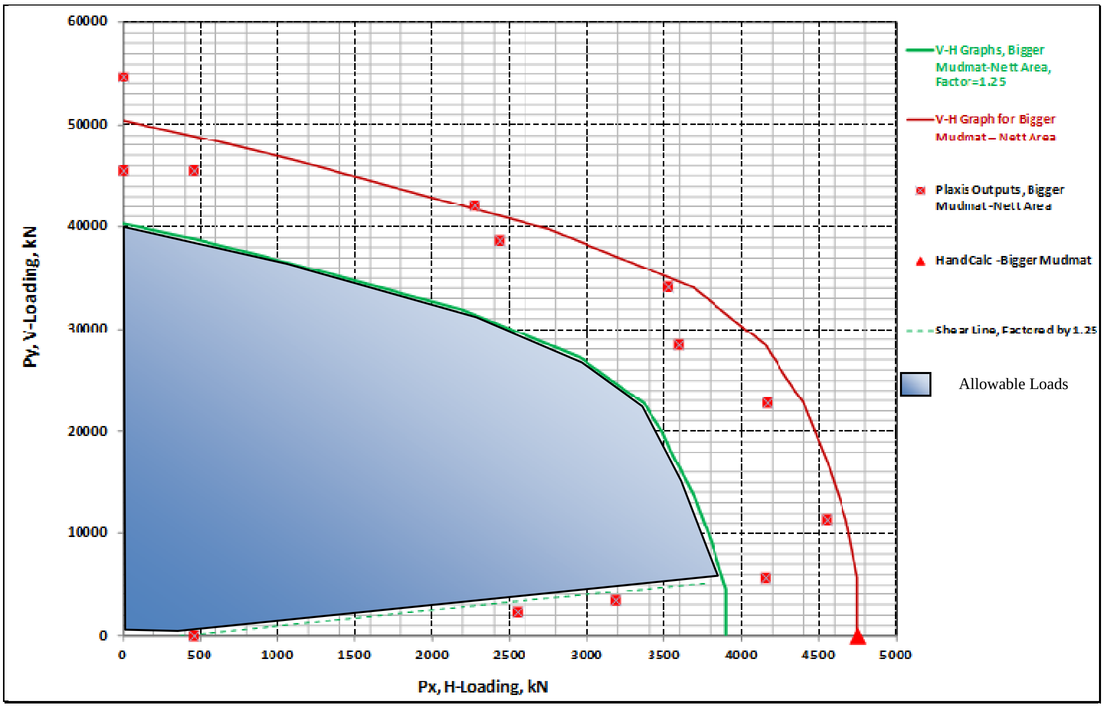

Figure Mudmat bearing capacity graphs, GK Site

As part of the mudmat structure, the mudmat skirts help increase resistance to horizontal loading, which was incorporated into the FE modelling for the GK jacket mudmats.

The FE modelling helped to understand the failure mechanism of the soils loaded by the mudmats at the GK jacket. The FE modelling revealed that, at the GK jacket site, the weakest place would be on the soft clay immediately underlying the top sand and sliding failure would mainly occur at the interface between the top sand and the soft clay immediately below the sand, i.e. at 1m depth below seabed. Based on such failure mechanism, a hand calculation of the sliding resistance was made which was also taken into consideration for the mudmat design.

The paper also briefly presents the skirt penetration analysis, which was performed based on the high soil strength profile, to ensure the target skirt penetration depth achievable.

The FE modelling, together with simplified analytical analyses, has led to final development of the bearing capacity envelope (see Figure enclosed) and facilitated finalising the design of the mudmats for the GK offshore project. The paper has also discussed the aspects of making improvements on the mudmat design and to mitigate the risk of offshore pile installation related to mudmat stability.

The investigation of the GK jacket mudmat stability has demonstrated how the geotechnical challenge could be met with the right strategy and holistic approaches. The design practice has provided useful reference information for defining the bearing capacity envelope of a skirt mudmat and would help design mudmats for future offshore projects, especially for those with similar soil layering setting up and mudmat/skirt make-up.

Reference

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