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Hybrid Mudmat Foundation for Offshore Structures: A Review

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ABSTRACT

Nowadays, the offshore industry has taken the lead in the advancement of civilization. In the global economy, oil and gas are crucial commodities. As a result of this, numerous offshore structures are upcomig worldwide. A large structure with facilities for drilling wells, extracting oil and gas, processing it, and exporting the finished product to shore is referred to as an offshore structure. Special equipment are needed for the development of subsea oil and gas fields. The structure must be reliable enough to protect the environment and make the economic viability of undersea hydrocarbon exploitation possible. In order to prevent offshore structures from sinking into softer, unconsolidated soil on the seabed, mudmat foundations are employed. But, when a structure is subjected to significant horizontal and vertical loads in a deepwater project, a conventional mudmat foundation is proven to be inadequate. The size of the mudmat needs to be increased, which is not practicable. Therefore, a Hybrid mudmat foundation might be more appropriate. Hybrid mudmat foundations are combined foundation system of mudmat and piles.This technology can significantly cut costs and makes use of the pile's and mudmat's lateral and vertical resistance. A review on Hybrid mudmat foundation for offshore structures is presented in this paper. Conclusions drawn from numerical analyses of Hybrid mudmat foundation are presented.

Keywords: Hybrid mudmat foundation, mudmat foundation, numerical analysis, offshore structure

INTRODUCTION

Facilities constructed away from the shore are included in the broad category of offshore structure. These structures make it possible to produce valuable resources like gas, electricity, and oil. Different offshore facility types meet various demands. The most prevalent offshore constructions are most likely oil and gas platforms. The platforms come in two varieties: The fixed structures that stretch to the ocean's bottom and the floating structures that float close to the surface. The floating structures are recent as compared to fixed structure. The oil platforms are specially protected against corrosion. The production of electric power is greatly aided by the wind farms. The installation of wind turbines offshore is preferred because they produce more electricity with a higher level of efficiency than wind turbines onshore. Higher levels of electric energy are produced due to the stronger winds over the ocean and offshore structure for subsea pipelines.

To extract oil and gas in those areas where it is impossible to do so with current technologies, the offshore industry needs the sustainable development of fresh approaches. The constant rise in human energy use has resulted in resource depletion in many places of the world. Only 10% of the entire hydrocarbon reserve has been discovered, and it is found in offshore locations to the tune of 30%. Techniques are needed for the exploration of these resources. The industry's ability to increase its operations in the marine environment is a major factor in its financial development. Therefore, the majority of advancements in offshore engineering are focused on recovering these resources. The geological characteristics of the seabed beneath deep water are typically very poor, which presents challenges during the design phase of structure foundations.

There are numerous foundation types used in offshore holding structures. The equipment it must support and the soil type on the installation location will influence type of foundation use. It can be divided into deep foundations and shallow foundations. Each type of foundation have its own significance. When layer of soil is of soft clay, deep foundation is feasible. However, when soil is over consolidated or dense sand with high bearing capacity shallow foundations are preferred. Shallow foundations are categoried as Gravity based foundation, Spudcan foundation and Mudmat foundation.

In the subsea production system, mudmat foundation is frequently employed as production infrastructure to support important components including wellheads, pipeline end terminations (PLET), pipeline manifolds and jacket structures. Mudmat foundations normally have a plane with a square or rectangular shape and a dimension of 3 to 30 metres. Depending on the soil conditions of the seabed, mudmats are typically skirted. The purpose of a mudmat is to offer enough space for the soil to distribute the load. Mudmats are made to withstand the weight of structures as well as any additional loads brought on by the surrounding environment. Typical mudmats have a top plate and many perpendicular vertical stiffeners that serve as load-bearing beams. The vertical resistance of the soil provided by the soil's bearing capacity, as well as the structure's resistance to sliding and overturning, are the key factors that must be taken into account when designing mudmats. Figure 1 shows typical mudmat foundation.

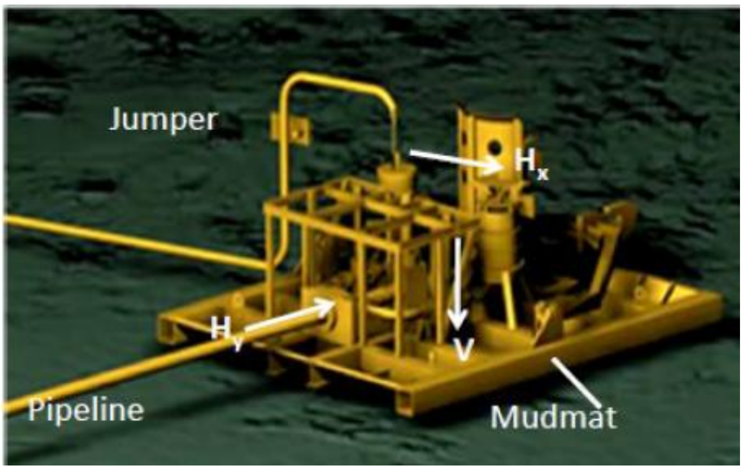


Figure 1: Typical Mudmat foundation

The extraction of oil and gas resources are carried out by providing subsea structure in deepwater. Mudmat foundation is used to supporting those structure and prevent the structure from sinking into the ground. But, in some circumstances, such as those involving extremely poor soil, constrained area on brownfield sites, or foundation size restrictions imposed by the installation vessel, mudmat alone might not be sufficient. So in this situation, hybrid mudmat foundation has been found to be helpful. Hybrid mudmat foundations are combined foundation system of mudmat and piles. When loads are more than a standard mudmat foundation's carrying capability but not as high as to warrant a costly deep foundation, a hybrid subsea foundation is an attractive option. This method limits the area of the mudmat and offers improved resilience to heavy horizontal loads in addition to vertical loads. Figure 2 shows typical Hybrid mudmat foundation.

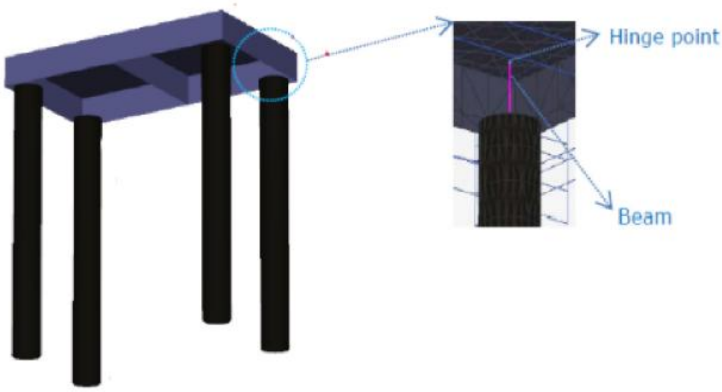


Figure 2: Hybrid Mudmat foundation

LITERATURE REVIEW

P Dimmock *et al.* (2013)[2] conducted research on Hybrid subsea equipment foundations with the focus of potential economic benefit of using HSFs in deepwater subsea developments, where the need for ever-larger installation vessels and higher associated costs arised from the need for mat sizes to resist typical subsea foundation design loads. Similar to analytical modelling, the model's geometry, design loads, and soil condition were all present.

ABAQUS software was used to conduct the analyses. For the pipeline and end termination in the Gulf of Mexico, particular mudmat and loading combinations were taken into consideration.A hybrid subsea foundation with a pinned connection to the mat corners was investigated. A FEM model of a hybrid subsea foundation and a mat foundation alone was constructed for numerical modelling. The soil was modeled as elastic –perfectly plastic. Mohr coulomb criteria was used for soil. The model's width and length were set to five times the appropriate foundation dimensions, while the depth was modelled at six times the foundation length.The vertical load remained constant and design loads were applied to a reference point located at the top of the mat's geometric centre. Figure 3 shows Load vs displacement response from the numerical combined load analysis.

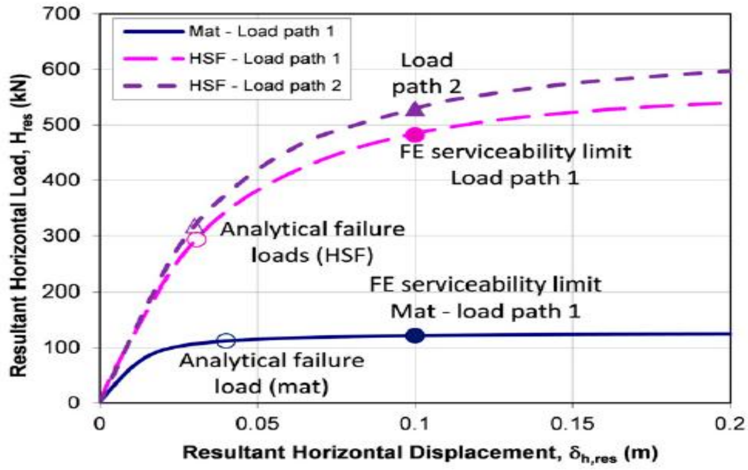


Figure 3: Load vs displacement response from the numerical combined load analysis

Through physical, analytical, and numerical behavior, they demonstrated the design viability of hybrid subsea foundation facilities in soft clay. They concluded that a significant increase in foundation capacity can be achieved by adding short piles to an existing mat foundation by placing them at the mat corners.

M. Kabir Hossain *et al*. (2015)[8] carried out a numerical analysis of the mudmat pile foundation's behavior as a Hybrid integrated system. Mudmat, corner piles, the pile-mudmat connection, and sea bed soil were taken into account in the FEM numerical analysis. The sensitivity of a hybrid subsea foundation to pile size, pile connection type, and pile number was examined. In order to better understand the different crucial design factors of an HSF and how they affect its behavior and capacity, a numerical research was done. . A 20-node reduced integration quadratic solid element was used to model the seabed soil. Mudmat and piles were modeled as 4- node reduced integration shell elements. The mudmat was setup such as to behave as rigid and piles were assumed fully plugged with soil. The seabed soil was modelled as an elastic plastic material obeying von mises criterian. Figure 4 shows V- H interaction diagram for hybrid subsea foundation

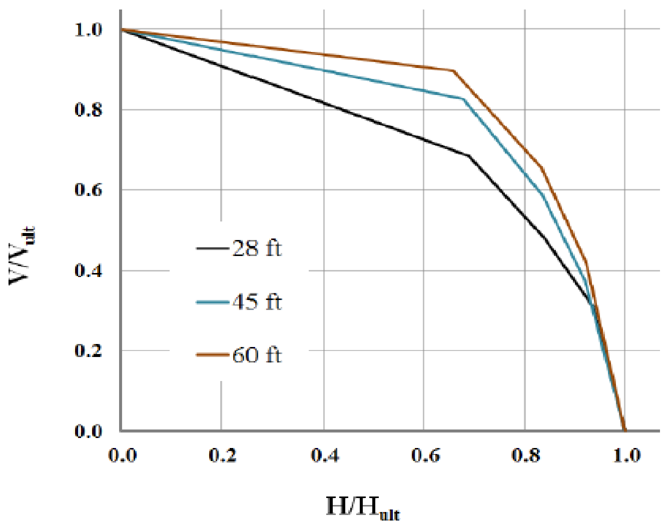
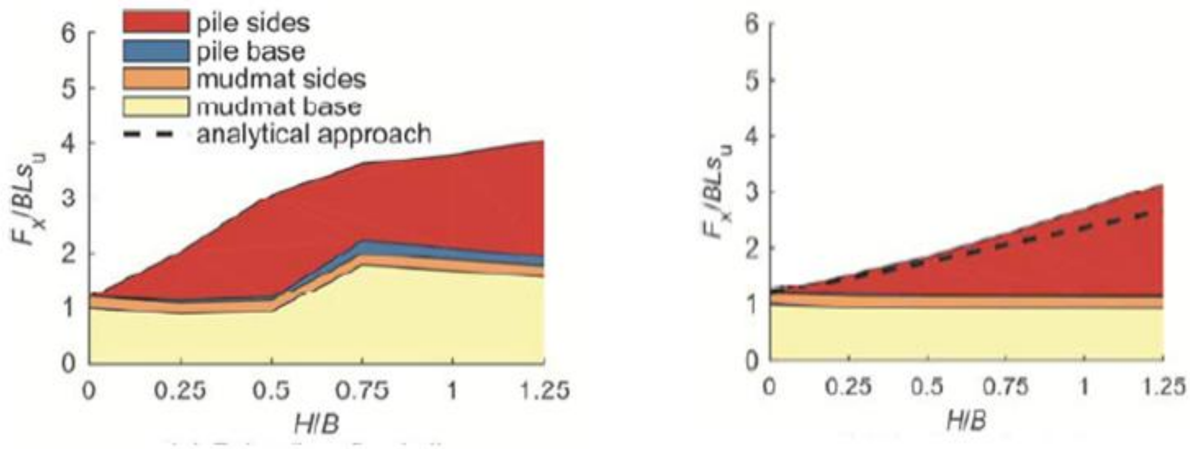


Figure 4: V-H interaction diagram for HSF

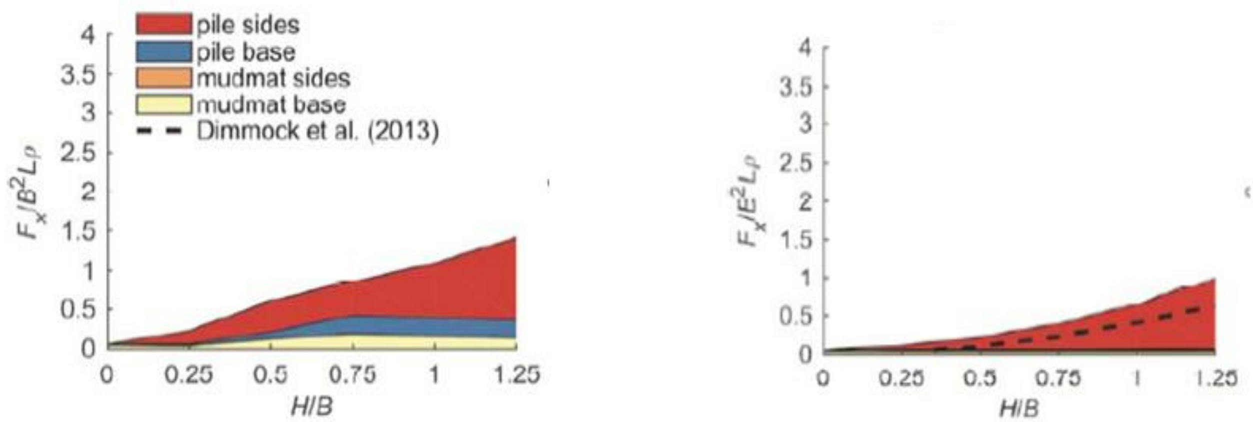
They concluded that In comparison to sliding connections, rigid mudmat-to-pile connections had more capacity. The vertical and horizontal HSF capabilities were directly impacted by pile length. Increased pile diameter has a minor tendency to increase HSF's lateral capacity, but it doesn't seem to have much of an impact on its vertical capacity. The V-H interaction plots showed that the HSF's vertical capacity tended to be less and less affected by the horizontal load as pile length increased.

HP Dunne *et al*.(2017)[3] carried out numerical investigation to ascertain the capacity of a mudmat foundation and hybrid foundation in clay under combined torsional and horizontal loads using three-dimensional (3D) finite element limit analysis. Three-dimensional analysis was utilised to assess the capacity of the hybrid foundation in both uniform soil and normally consolidated soil, while plain strain analysis was employed to validate the usage of simplified polygonal pile cross sections. OxLim software was used to carried out the analysis. Two cases of pile head restraint of pinned and fixed was considered in the analysis. Two soil profiles of uniform soil and normally consolidated were taken into consideration. The undrained soil was modeled as rigid plastic Von Mises material. It was assumed that the mudmat sides were smooth and base of mudmat piles sides was fully rough. The open-source mesh generating programmes Triangle and Tet Gen were utilised in the 3D and plane strain analyses of OxLim. For each analysis, the final refined mesh included about 40,000 elements. Figure 5 and 6 shows total capacity for uniaxial loading in uniform soil and normally consolidated soil respectively.



a) F_x loading, fixed piles **(b) F_x loading, pinned piles**

Figure 5: Total capacity for uniaxial loading in uniform soil, divided into component contributions for hybrid foundations with a range of pile length, and pinned or fixed pile heads.



a) F_x loading, fixed piles **(b) F_x loading, pinned piles**

Figure 6: Total capacity for uniaxial loading in normally consolidated soil, divided into component contributions for hybrid foundations with a range of pile length, and pinned or fixed pile heads.

They concluded that when piles were fixed rather than pinned, the capacity of a hybrid foundation was significantly higher for various length of pile and for various diameter of pile the capacity of pinned pile had not much difference while in case of fixed pile the capacity was increased in hybrid foundation.

Sehoon jang *et al*. (2017)[9] carried out numerical stimulations in order provide a better understanding of the impact of multidirectional loading on the capacity and displacements hybrid foundation system by creating 3D failure envelopes. The pattern of soil resistance mobilizations was also taken into consideration to predict the soil structure failure mechanisms and displacement of Hybrid subsea foundation. They considered that the Subsea hybrid foundation was provided in deepwater of Gulf of Mexico. The soil was modeled with width equal to five times the PLET width and length measured from its edge in both directions and Vertical boundary was taken as 2 times pin pile embedded length. Mohr- coulomb model was used in analyses.Different capacities, including displacement and rotation under maximum design loads, vertical and horizontal combined capacities with calculated factors of safety, maximum vertical and horizontal capacities, and ultimate vertical, horizontal, overturning moment, and combined load capacities, were examined in order to develop the 3D yield surface. Figure 7 shows yield surface output for PLET hybrid foundation.

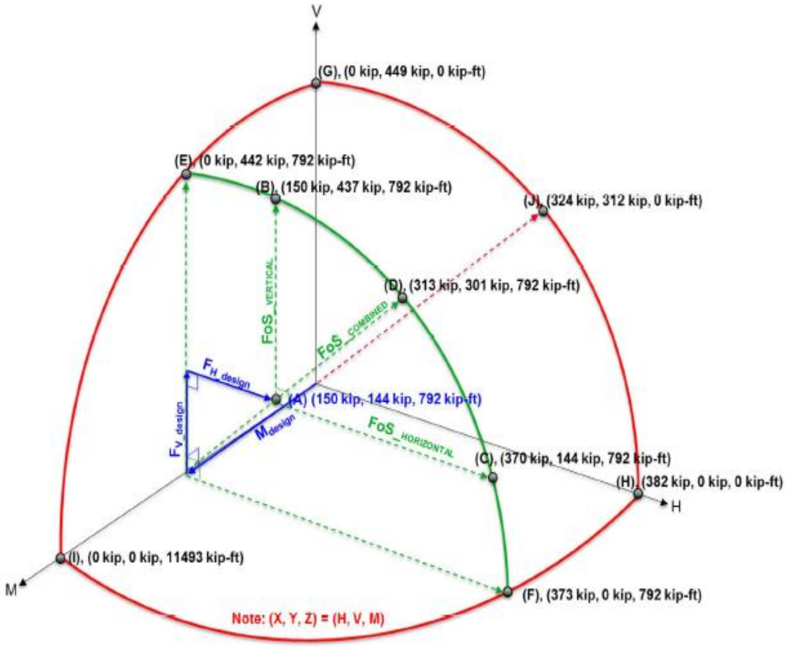


Figure 7: Yield surface output for PLET hybrid foundation.

For obtaining capacity of PLET, additional load was gradually applied at the geometric center of mudmat. The application of additional load was continued until vertical displacement exceeded 10 % of mudmat width or until the foundation failed. They concluded that the soil mobilization vectors proved the deep foundations exhibited strong early lateral and vertical loading resistance, whereas shallow foundations exhibited gradually rising resistance as the load was imposed. The yield surface provided significant moment resistance.

Desen kong *et al*.(2018)[1] carried out numerical stimulation to predict the performance of subsea mudmat pile hybrid foundation. The investigation was done for various load combinations using a numerical model of a subsea mudmat-pile hybrid foundation. The analysis was carried out by FLAC 3D software. Location of analysis was South China sea and depth of water was taken as 200 m. The soil was saturated soft clay based on actual conditions of South China sea. For seabed soil, the Mohr-Coulomb model was used. The analysis involved examining the characteristics of the composite foundation under three different combinations of loads: a vertical load and a horizontal load, a vertical load and a bending moment, and a horizontal load and a bending moment. Settlement analysis of the seabed soil, bending moments of anti-sinking plates (mudmats), displacement along pile shafts, and bending moments along pile shafts were presented for each load combination. Under different loading conditions, the force and deformation characteristics were investigated. Figure 8 shows settlement of the seabed soil.

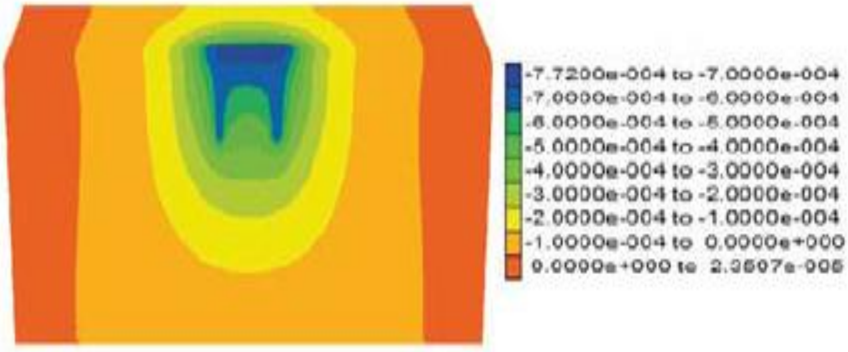


Figure 8: Settlement of the seabed soil

They concluded that the combined load caused the seabed soil next to the mudmat-pile hybrid foundation to settle, whereas the soil far from the foundation was somewhat uplifted and the range of influence of the pile foundation's presence on the seabed soil's settlement was roughly two times the length of the pile body. The piles were most susceptible to damage at the connections between the pile tops and the anti-sinking plate under a combined load.

CONCLUSIONS

From the brief review on hybrid mudmat foundation following broad conclusions are drawn

1. The capacity of mudmat foundation increase significantly by provision of short piles placed at corners.
2. The rigid mudmat- pile connection had more capacity than that of sliding connection.
3. Pile length has more influence in capacity of hybrid mudmat foundations.
4. The capacity of hybrid mudmat foundation is greater when connection of mudmat - pile was fixed rather than pinned.
5. The seabed soil near the hybrid mudmat foundation subjected to combined load causes settlement of two times the length of pile in hybrid mudmat foundation.

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