



RESEARCH ON METHOD OF UNDERWATER FIXATION OF UNDERSEA STRUCTURE

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ABSTRACT

With the increasing depth of offshore oil exploitation, underwater fixed foundation becomes a key part of ocean engineering. A thorough understanding of the characteristics and purposes of these structures will contribute to the development of deep-sea oil industry. In this paper, the advantages, disadvantages and applicable range of pile foundation, suction anchor and mud mat are analyzed. In view of the existing problems, an improved method is put forward, which can provide guidance for the undersea fixed foundation of marine development.

Key Words: pile foundation; suction anchor; mudmat; fixation method

Introduction

With continuous increase of global demand for energy, offshore petroleum development gradually develops to the scope of deep sea, even ultra-deep sea, so traditional offshore petroleum equipment has not adapt to development of deep sea oil and gas^[1]. In recent 20 years, offshore petroleum development has extended from hundreds meters to thousands of meters of water depth, in the course, people gradually have some basic knowledge of characteristics of structural form and foundation form of various oceanic engineering. As traditional basic form of undersea fixing, pile foundation^[2] plays significant role in development of marine oil and gas. But it gradually shows limitation in deep sea development. As a new type of undersea fixing foundation, Suction anchor^[3] has a good prospect with wide application range, gradually become a main form of marine foundation fixation in place of pile foundation. Mud mat^[4] is widely used in underwater production system due to its simple structure and convenient installation. This paper provides instruction for fixation of underwater structure of future marine engineering mainly by analyzing working principle, application, merits and drawbacks of pile foundation,

suction anchor and mud mat, proposing improvement suggestions aiming at their respective problems.

1 Pile foundation fixing method

2.1 Working principle and classification of pile foundation

Pile foundation typically consists of pile body and bearing platform. In pile foundation, the sectional size is much smaller than that of length. Working principle of pile is to use the pile to pass through soft soil layer, transmit upper load to compact or hard soil layer under pile foundation, reduce pile foundation sink under gravity of structure and shifting of structure under horizontal load^[5].

According to force condition, pile foundation can be divided into friction pile and end bearing pile. Friction pile uses friction between earth layer and base pile to bear construction, it can be divided into pressure pile and tension pile, used in application without hard geographic bearing bed or with deep bearing bed. End bearing pile is that the base pile is seated on bearing bed (on laccolith) to bear load. Based on construction method, it can be divided into precast pile and cast-in-place pile. Precast pile is to drive precast reinforced concrete pile underground using a piling machine. Its advantage is saving material, high strength, suitable for buildings with higher requirements, its disadvantage is high difficulty of construction, long construction period due to limitation of quantity of machine. The filling pile is to drill holes in construction site first, put in rebars and poured concrete when needed depth is reached. Its advantage is low difficulty of construction, especially manually digging pile holes is not limited by quantity of machine. If all pile foundation can be constructed simultaneously, it would be saving time greatly. Its disadvantage is low bearing capacity and wasting material.

2.2 Application of pile foundation in Marine Engineering

As traditional undersea foundation fixing form, pile foundation plays significant role in marine engineering, especially in shallow sea. In terms of marine petroleum, offshore jacket platform typically uses large diameter open steel pipe pile (typically within 300m), fixing four ends of offshore platform by using effect of group pile as fixed foundation supporting the platform, and pile foundation can also use its upper anchoring effect to moor the drilling ship or drilling platform by stretching and drawing braced chain system^[6](as shown in Fig 1). In terms of offshore wind power generation, offshore wind power generator depends on pile foundation fixed on seabed, effectively resisting wind, wave and sea current load. In terms of bridge construction, use reinforced concrete pile as bottom foundation to bear upper large load, preventing upper structure from large deformation.



Fig. 1. Bohai Bay Jacket Platform

2.3 Advantages and disadvantages of pile foundation

Currently pile foundation is a relatively proved traditional undersea fixing foundation, typically driven in with a pile hammer or drilled in with a drilling ship. Application of pile foundation in ultra-deep water is restricted to some extent because the pile hammer has high requirement for ship when water depth is above 2000 m, and overall price of construction is also high, and bearing capacity of drilling pile is influenced by mode of installation^[3]. Secondly, hammer blow of pile driving equipment during penetration of pile foundation will produce environmental noise, and pile foundation also produces shifting easily. In order for penetration of pile foundation in given direction, a guiding device needs to be used. When the pile foundation penetrates to given depth, it cannot move to other place to work during fixing underwater. In addition, offshore installation of pile foundation needs long period, consuming large amount of steel, resulting in high overall costs of pile foundation.

Yet, pile foundation also has certain superiority. pile foundation mainly uses hard stratum at bottom of pile foundation, so it features high bearing capacity, good stability and small settlement. Pile foundation mainly bears vertical load, it also adapts to larger eccentric load, horizontal load, periodic load, etc. In terms of construction, marine engineering often uses pile forming method of pouring, which is less difficult.

2 Suction anchor fixing method

3.1 Structure and working principle of suction anchor

Suction anchor is also called suction pile, bucket foundation or suction caisson. The structure of suction anchor is a bucket structure with upper end open and lower end closed, mainly bearing huge horizontal, vertical load and bending moment. Its diameter is typically 3~12 m, length-diameter ratio normally 1~6^[7], wall thickness-diameter ratio typically 0.3%~0.6%, thickness of bucket wall mostly takes 15~50 mm. Side wall of bucket is steel material, and top cover is typically steel and reinforced concrete material. On top of the anchor

bucket is left a water drawing hole connected with a vacuum pump. In terms of fixation of undersea structure, suction anchor typically consists of one or multiple anchor bucket^[8].

Main mechanism of suction anchor is principle of vacuum. When the suction anchor contacts seabed, it continues to sink due to gravity, forming initial penetration into mud. Now continue pumping water and mud in the bucket with a vacuum pump, when pumping rate is more than flow rate of water seeping into the bucket from bottom of the bucket, vacuum is formed in the bucket producing negative pressure. Use differential pressure between inside and outside the bucket to sink the suction anchor to given depth. At last remove the vacuum pump to balance pressure inside and outside the bucket, installation of suction anchor is finished. When it is needed to reversely pull out the suction anchor foundation, we can jack the bucket from mud by making the pump work reversely, namely injecting water into the bucket to make pressure inside the bucket higher than outside the bucket^[9]. The working principle is shown in Fig 2.

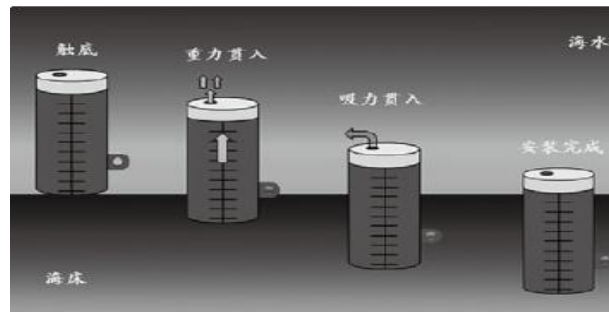


Fig. 2. Working principle of suction anchor

3.2 Application of suction anchor in Marine Engineering

In recent years, suction anchor foundation is used in marine engineering more and more widely, the research on suction anchor also makes great success. Especially for marginal oilfield with relatively complex deposit structure, small reserve, high cost of development, application of suction anchor foundation is of economic significance.

(1) Suction anchor is used as offshore structure mooring system (as shown in Fig 3), such as single point mooring, pulling of traction platform, ship mooring, fixation and traction of lines;

(2) Suction anchor is used as foundation of platform structure, such as jacket platform, tension leg platform, foundation of offshore wind power generation unit, etc.;

(3) For underwater production system, in deep water above 300m deep and ultra-deep water above 1500 m deep, most underwater production systems adopt suction bucket foundation to fix. As shown in Fig 4

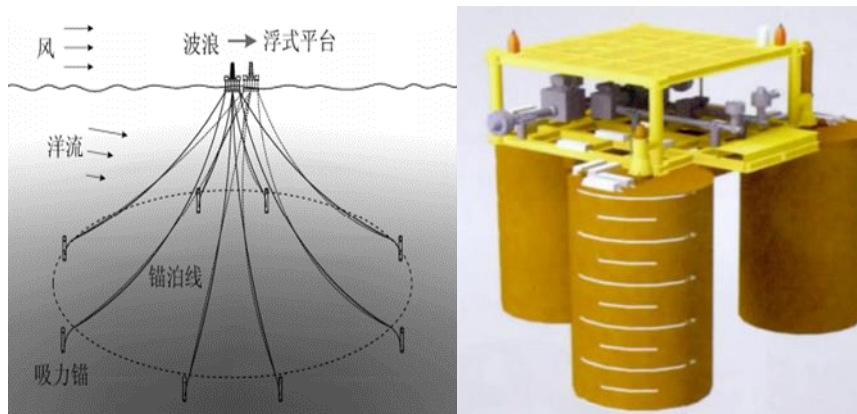


Fig. 3. tight / semi tensioned suction anchor mooring system of subsea manifold

Fig. 4. Suction anchor as the foundation

3.3 Advantages and disadvantages of suction anchor

Suction anchor is mainly used in marine engineering, simple to construct, safe and reliable, able to be reused in different places, wide soil property adaptability, etc. In terms of function, suction anchor can bear large horizontal force and twisting torque, can provide mooring force for ships, can also be used as foundation structure of construction such as offshore platform^[10]. Meanwhile suction anchor uses negative pressure sinking installation, shortening operation time and speeding up progress of installation, consequently saving installation cost. Furthermore suction anchor foundation can effectively save steel consumption compared to traditional foundation, so suction anchor has good economic property and development prospect. Yet suction anchor also has deficiencies. For example, during penetration, due to plugging effect, top of suction anchor can contact seabed in advance making bucket fail to penetrate to given depth, and when encountering hard strata, suction anchor does not also have good penetration effect.

3 Mud mat foundation fixing method

4.1 The working principle and classification of mud mat foundation

Mud mat functions evenly distribute upper load, such as weights including manifold structure and its jumper pipe etc. on seabed to reduce settlement of structure. Size of drilling template depends on undersea environmental condition, the softer the soil, the larger the size of mud mat. To facilitate installation of mud mat and increase stability of mud mat, reduce dimension of mud mat, skirt plate is added surrounding mud mat, skirt plate directly penetrates into given depth of mud, providing horizontal shear resistant intensity to overcome horizontal load and its vertical load^[11].

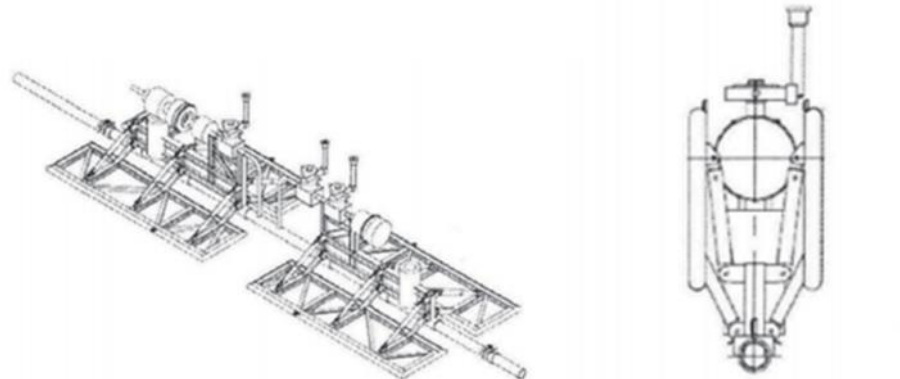
Mud mat is divided into integrated, folding and separate types based on structural form^[12].

(1) Integrated type, when geologic condition is good or fishing net protection does not need consideration, size of mud mat can be made small, to save cost, equipment, fixing and supporting structure and mud mat can be integrated to conduct integral installation.

(2) Folding type. When considering using pipe-laying ship to install, if using structural form, mud mat can be designed as folding type. During laying down of pipe-laying ship mud mat can be folded to ensure mud mat able to extend through tensioner to meet requirement for bearing

capacity after being laid down on seabed, as shown in Fig 5.

(3) Separate type. Limited by lifting capacity of installation ship, manufacture upper equipment and mud mat separately, during installation lay down mud mat first, then install upper equipment.



(a) before folding (b) after folding

Fig. 5. sketch of folding mud mat

4.2 Application of mud mat in Marine Engineering

Mud mat foundation plays important role in seabed production system, bearing load of every blocking of seabed production system and transfer it to the foundation, it is the foundation of every blocking of seabed production system. It plays supporting role at underwater wellhead, manifold node, umbilical cable (as show in Fig 6). In terms of jacket platform, mud mat effectively supports upper load by connecting lower jacket, preventing jacket platform from settlement.

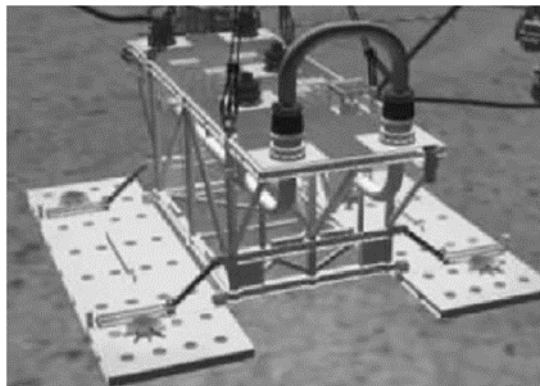


Fig. 6. suction anchor as the foundation of subsea manifold

4.3 Advantages and disadvantages of mud mat foundation

As foundation bearing form of undersea structure, mud mat features simple structure, convenient installation, light weight, small investment, etc. It is suitable for soft soil, now mud mat has large superficial area, but too large mud mat can influence installation, and increase difficulty of leveling mud mat.

4 Improvement of Fixing method

The development of the pile foundation mainly focuses on the section diameter, sectional shape and the change of the pile-soil interface^[2]. In the different positions of equal diameter drilled holes, the enlarged body which is larger than the original equal diameter drilled or squeezed can be drilled or squeezed by the construction technology, thereby improving the bearing capacity of the pile and reducing the engineering cost. Secondly, by using the cross section of non-axisymmetric cross section, the vertical shape of the pile body can be changed, and the bending resistance and the lateral friction of the pile can also be improved. Finally, the contact strength between the soil around the pile and that at the end of the pile can be improved by a certain process, and the bearing capacity and the settlement of the pile can also be improved.

During suction penetration of suction anchor, because negative pressure suction and seeping force can form plugging effect, hindering continuous penetration of suction anchor, failing to reach installation depth. Aiming at the problem, impulse suction penetration can be adopted, manually controlling on and off, suction of immersible pump to form impulse suction, reducing difficulty of penetration. Randolph^[13] proposed that outer edge of opening end of suction anchor bucket can be filleted to reduce plugging effect.

During laying down of larger mud mat, because drag force of sea current will result difficult laying down of mud mat, making mud mat bottom the form of slit^[14], effectively increasing open area of sea current, increasing reliability of laying down of mud mat. In terms of bearing capacity of mud mat, arrangement of bottom skirt plate can be changed^[15], the deeper bottom structure penetrate into mud, the larger side projection area, the more obviously bearing capacity increases.

5 Conclusion

Its structural features, working principle and applicable scope is researched through above analysis. It is known through comparison that mud mat foundation is an undersea structure foundation featuring simple structure, convenient installation and minimum investment, if soil condition and load is appropriate, mud mat foundation is preferred. When horizontal force is large, mud mat with skirt plate cannot provide bearing stability, it is appropriate to select bucket foundation. when lacking engineering geologic parameters, horizontal load is too large, when in shallow water no ore than 300 m deep, pile foundation shall be selected. To reduce influence of plugging on drag force during laying down to seabed of suction anchor, impulse suction can be adopted to effectively reduce height of plugging. In terms of mud mat, changing arrangement of skirt plate, increasing penetration depth into mud and side projection area, bearing capacity can be increased obviously.

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