Model study of Bucket Foundations Platform with new installation method

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Abstract

Bucket Foundations Platform (BFP) is an innovative and cost-effective ocean platform. BFP may be founded in seabed by suction, and easily be drawn out for relocation. To cater for an urgent need of China marginal oil field exploitation, a pioneer BFP with a new installation technique is introduced in this paper. The installation of a BFP is a crucial process in reducing time and cost of an offshore operation. This study examines the innovative installation method, namely the self-ballast mooring installation method, which allows a BFP to be sunk down and founded from tow draft to seabed without the assistance of a vessel. The motion characteristics and mooring requirements of a model BFP during the installation are experimentally examined in a wave basin and the main findings are presented.

The study shows that the proposed installation method is feasible in the wave-current environment tested. The most significant parameters affecting the motion of the BFP and mooring tension are wave direction, amplitude and period. Current has a relatively minor influence. During the sinking operation, magnitude of motion in most directions decreases, but surge and mooring line tension shows opposite trend. The motions may be further reduced by other means during the sinking operation.

To date, only two BFP were installed in North Sea during the 90’s. However, the method of installation in the North Sea may not be economical in marginal oil field, where the new installation method of BFP can play an important role. The new method of installation together with the ease of reusability is the key to realize the economic exploitation of marginal oil fields.
1 Introduction

The continental petroleum and natural gas resources have been widely exploited. In the future, further oil output will mainly rely on offshore oil fields. The proved offshore oil reserves are 250 billion tons presently, about two times of continental oil reserves. Offshore exploitation of petroleum and natural gas has a tremendous potential in catering for the development of world economy.

However, it is also found that comparative portion of offshore oil reserves is marginal oil field reserves, where reserves of petroleum and natural gas in single oil field is relative low. For instance, 500 million tons of total 1.4 billion tons oil reserves in China offshore areas belong to marginal oil field [1]. If we exploit this kind of oil fields in traditional fixed production platforms, it will produce little or even no profits. There is an urgent need of new technologies in marginal oil field exploitation.

Bucket Foundation Platform (BFP) is an innovative and cost-effective platform, can be used in wide range of water depth and different kinds of soil base. Substituting the traditional pile foundations with bucket foundations, BFP may be founded in seabed by suction, and be drawn out for relocation. This great innovation changes the seabed fixed platform into mobile platform. Using of BFP makes it possible to enormously reduce the platform cost of single oil field.

Research on bucket foundation platform started from suction structures. Helfrich [2] found the pull out characters of suction anchor in sand, and provided detail data of small suction anchor of 400 mm in diameter. Wang et al [3] put forward the equations of anti-pull capacity based on suction structures experiments in diameter of 114 mm to 337mm. Tests by Hogervorst [4] found that a bucket foundation of 3.8 in diameter, 5 m to 10 m in length could provide maximum anti-pull capacity of 200 tons. Xu et al [5] used bucket foundation as the anchor for small offshore monitoring system. In 1991, Bucket foundations were firstly used in SNORRE oil field of North Sea as large suction anchors for tension leg platform [6]. In 1994, bucket foundations came into use in EUROPipe 16/11E BFP of North Sea oil field successfully [7].

There are only two BFP installed nowadays. However, both of the BFP are large platforms with bucket foundations and traditional brace structures, and offshore installation of BFP still needs assistance of crane barge. It is therefore not economical to use this kind of large BFP in medium or small-sized marginal oil fields. To exploit marginal oil fields widely distributed around the world, mini-BFP with new structure and cost-effective offshore installation method is necessary.

In this paper a pioneer single-pillar BFP is introduced. The installation of BFP is a crucial procedure in reducing time and cost of offshore operation. This study puts forward the innovative installation method, namely the self-ballast morning installation method, which allows a BFP to be sunk down and founded from tow draft to seabed without the assistance of crane barges. The motion response and mooring lines tension of a model BFP during the installation were experimentally examined in a wave basin [8]. The study shows that the proposed method is feasible in the wave-current environment tested.
2 Single-pillar BFP with new installation method

According to the design requirement for marginal oil field, the new BFP is not an integrated platform with full function, but a simple production platform. When the deck load is relative small, it is more economical to choose single pillar rather than jacket. Based on analysis of environment forces, three bucket foundations were adopted. In order to realize new method of self-ballast morning installation, another structural unit, namely cone-shaped pontoon module was designed. The pontoon is a knock-down module that is fixed on the top of bucket foundation. When the BFP is towed to oil well, the pontoon modules can provide enough buoyancy. In the operation of BFP installation, the pontoon modules will make the BFP stable under the action of environment forces. Structure of single-pillar BFP is shown in figure 1.

Offshore installation of platform is an important operation for construction of ocean oil fields. Normally the installation needs large crane barges and many other assistant vessels. The operation also should be finished in certain weather window with high efficiency. The pontoon modules make BFP to be installed with new method, namely self-ballast morning installation. After the BFP is located on the well position, four anchors are cast at corners. Then ballast water is added into pontoons, the BFP sink down steadily. At the same time, the mooring lines are strained, which keeps the BFP on the right position and decreases the motion response of BFP greatly.

![Structure of BFP](image-url)
Since the sinking speed of the BFP is comparatively low, it is reasonable to control the sinking speed through adjusting the dynamic velocity of ballast water in pre-calculated value. Also the mooring lines are strained in certain speed according to the sinking speed of the BFP, see figure 2.

The new method of self-ballast morning installation doesn’t need large assistance engineering vessel, the offshore operation time is short, it will largely decrease expense of offshore installation, and enhance the construction efficiency of oil field. Model tests were made to validate the feasibility of the new installation method, and to know the motion response of the BFP under environment force.

3 Experiments set up

The experiments were done in a large wave basin of 50m in length, 30 m in width and 6 m in depth. Based on the dimensions of BFP and the wave basin, the reduced scale of BFP model was determined as 25. The environment condition simulation for BFP installation included current and irregular wave. The design velocity of current is 1 m/s. The wave is P-M spectrum, wave amplitude, $H_s$ is 2 m; Characteristic period is 5.32 s; Wave crest period is 6.889 s.

The BFP model floated in wave flume as shown in figure 3. Four mooring lines were set up in direction angle of 45 degree, 135 degree, 225 degree and 315 degree. Six direction of BFP motions including surge, sway, heave, pitch, roll and yaw were measured by potentiometers connected with the deck of BFP, tension of four mooring lines were measure by tension transducer stuck on mooring lines.
4 Analysis of Tests Results

4.1 Motion response of BFP and tension of mooring lines

Figure 4 to figure 8 show the BFP motions of 12 m in draft under the action of wave. Yaw of BFP is absent since its amplitude is found very small in experiments. All the parameters have been transferred from model units into reality units. It is obviously that the motions of BFP vary periodically with time. There is stagnancy in heave and pitch due to connection error between potentiometers and BFP, but this phenomenon disappears later.

Main motion directions of BFP accord well with wave direction, namely longitudinal direction along the wave basin. The amplitude of surge is 1.6 m, the amplitude of pitch is 8 degree. Transverse motions of BFP are smaller than surge and pitch. The amplitude of sway is 1.1 m, the amplitude of roll is 4 degree. For the existence of bucket foundations, vertical motion damp of BFP is quite large. Hence the heave response is relative small, the amplitude of heave is only 0.4 m.

Response period of BFP differs in each direction. In the wave direction, response period is relative small. For example, time-domain response curves of surge and pitch are quite dense, while the response periods of sway and roll are large. Heave response has the similar period with surge. The floating BFP is moored in water. Difference of response periods is owed to the wave direction. In the directions of surge, pitch and heave, BFP is under direct action of wave. Hence the motions in these directions are mainly wave frequency. While sway and roll is transverse with wave spreading, they have a long period similar with the inherent period of BFP-mooring lines system.
Figure 4: Surge time-domain response of BFP.

Figure 5: Sway time-domain response of BFP.

Figure 6: Heave time-domain response of BFP.
Figure 7: Pitch time-domain response of BFP.

Figure 8: Roll time-domain response of BFP.

Figure 9 to figure 12 show the tension of four mooring lines. Four symmetrical mooring lines endure wave and current force when greatly decreasing motion response of BFP, especially in surge. Theoretically, two upriver lines tension of \( f_1 \) and \( f_4 \), and two down-stream lines’ tension of \( f_2 \) and \( f_3 \) should be same in the direction of wave spreading. But from figure 9 to figure 12, there seems some difference. It can be attributed to the pretension force adjustment error of the four mooring lines at initial stage. It is clear that \( f_1 \) and \( f_4 \) is large than \( f_2 \) and \( f_3 \) in both maximum value and overall distribution. Peak values of \( f_1 \) and \( f_4 \) are 32 \( t \) and 34 \( t \), peak values of \( f_2 \) and \( f_3 \) are 21 \( t \) and 25 \( t \) respectively. Since the irregular wave was adopted, tension of mooring lines is quite small in certain range of time domain.

Tension of mooring line also varies periodically with time. The period of four mooring lines is similar. Trend of tension changes analogously with surge response of BFP, and period of tension is similar with period of surge. It reflects the close relationship between the tension variety of mooring lines and surge response of BFP, the main restriction of mooring lines to BFP is on the direction of surge.
Figure 9: Tension of mooring line 1.

Figure 10: Tension of mooring line 2.

Figure 11: Tension of mooring line 3.

Figure 12: Tension of mooring line 4.
4.2 Effects of current

Another round of tests was made with additional action of current. Limited to the length of this paper, the figures are not presented here. From the comparison of results with and without current, it is found that current has finite impact on BFP motion. Only peak values of surge, pitch and heave have some increase. Surge varies from 1.6 m to 2 m, pitch varies from 8 degree to 11 degree, and heave varies from 0.4 m to 0.6m. Response periods of BFP have not significant change, as well as that of period of tension. Obvious effect of current is tension increment of upriver mooring lines. The tension goes up to 42 t in maximum.

4.3 Analysis of BFP sinking operation

Motion response of BFP and tension of mooring lines were tested when BFP sunk down to larger draft. It is found that the draft has significant effects on BFP motion and mooring lines. More parts of BFP will be submersed into water in sinking operation, which can increases the underwater damp of BFP, and the area of cross section under the action of wave and current.

Surge response increases appreciably in sinking operation, since there is large increment of bearing area for wave and current, although the damp increases at the same time. Other direction of motion response decreases for the reason of increcent damp. For instance, heave, pitch and roll fall as large as 50%. But there is no distinct variety of response periods in different directions.

Tension of all four mooing lines increase in the sinking operation. The maximum tension is about 50 t. The mooring lines are mainly used to restrict excursion of BFP, due to increment of surge, tension of mooring line will rise inevitable. The sinking operation seldom changes the period of tension, which is mainly determined bye wave period.

5 Conclusion

For the exploitation of marginal oil field, new type of BFP with innovative installation method is introduced in this study, and the method was examined in particular experiments. The new BFP is composed with single pillar, bucket foundations and pontoon modules. To realize economical offshore installation, self-ballast mooring installation method with the assistance of mooring lines and pontoons is presented.

Wave is the main factor influencing the motion response of BFP and mooring lines system. Amplitude of wave decides the magnitude of BFP motion and the tension of mooring line. The main motions of BFP are surge and pitch along the direction of wave. Period of wave determines the response periods of surge, pitch and heave, and the tension fluctuating character of mooring lines. Current is a stable force for the BFP-mooring lines system, obvious effects is the tension increment of upriver lines.

Surge response of BFP increases in the sinking operation, while motions of other directions fall down. There is no definite change of response period since it
is mainly decided by wave period. When the BFP gets close to seabed, motion response of BFP is still considerable large, for example, surge is 2.5m, pitch is 4 degree and heave is 0.2 m. Some further means can be adopted to reduce the motion response. The tension of mooring lines increase in sinking operation. Hence the design load of mooring system should be based on the tension of mooring lines in the maximum draft.

Model study shows that the new method of installation under the action of wave and current is feasible and stable. The proposed method of installation of BFP is economical and can be widely used in re-utilization of BFP, and has a great potential to be developed for marginal oil field.

Reference:


