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Subsidence monitoring of offshore platforms

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Abstract

The normal subsidence monitoring technologies, used in civil engineering, are hard to apply in ocean engineering. Because it is hard to find a fixed reference for subsidence monitoring. A new method, which is suitable for subsidence monitoring of offshore platforms, is proposed in this paper. Firstly, the compression characteristic of the soil was analyzed and the harms of subsidence are discussed. Based on the analysis, the subsidence monitoring method was given. Finally, an real application is shown. Some advanced measurement technologies, such as the FBG strain measurement techniques and so on, were used in this application. The real application indicates that the new method is suitable for the subsidence monitoring of offshore platforms.

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Keywords: subsidence monitoring; offshore platform; diffinetial settlement; FBG strain sensors;

1. Introduction

Subsidence is a relatively common phenomenon especially in civil engineering. The offshore platforms in shallow water also have the subsidence problem, as the harsh environment and the unsteady soil. The subsidence problem is relative to the conditions, such as the depth of the piles, the stability of the basal soil and so on. The deep base platforms, such as the jacket platforms, are more steadier than the shallow base platforms, such as the jack-up platforms. A jack-up drilling platform was blew down by a

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big wind condition in September 8, 2010, in Shengli oilfield. This accident is mainly cased by the subsidence problem.

The subsidence problem of offshore platforms is very popular in the world. Such as, in the fields namely Ekofisk in the Norwegian North Sea[1、2], Amoco's Eugene Island 367 Block; in the US Gulf of Mexico, the Valhall field platforms[3] and so on. Usually the platforms are very far away from the earth. Thus it is difficult to monitoring the subsidence problem as the usual civil engineering does, as it is hard to find a fixed reference for subsidence monitoring. Some researchers try to monitoring the subsidence problem using GPS technology[2、4、5]. It is effective and convenient for offshore platforms subsidence monitoring. But the precision is a little low and the long-term stability is hard to ensure. Furthermore, the GPS measurement technology is unenlightened in our country as the high-precision GPS service does not open to China.

Therefore, there isn't a suitable solution for the subsidence problem of offshore platform in China now. In order to solve this problem, some research work had been done in this paper. Firstly, the compression characteristic of the soil was analyzed, and the subsidence harms were discussed. Secondly, a solution for offshore platforms' subsidence problem was given through monitoring some information of the prototype platforms. Finally, a real application of the subsidence monitoring method, used on a jacket platform in Bohai Bay, was shown and the monitoring results were discussed.

2. Subsidence characteristic analysis

2.1. Compression characteristic of soil

The subsidence problem of structure is mainly caused by the deformation of the basal soil. The compression deformation of soil is nonlinear and unstable as the composition of it is very complex. The soil will be sheared under vertical loads. Caused by different boundary conditions, the shear failure of soil can be divided into three main forms, namely: general shear failure, local shear failure and piercing shear failure. The P-S curves of the three kinds of shear failures are as shown in Fig 1. Based on the shear failure mode of the soil, the compression deformation of soil can be divided into three stages:

The first stage, elastic deformation stage. When the soil is under a vertical load which is less than the critical force P_{cr}, the deformation of it will be linear and could basically restored if the load is removal. It means that the soil is elastic in this stage. We call the critical force P_{cr} as the plastic critical force.

The second stage, the plastic deformation stage. When the vertical load is bigger than the plastic critical force, the compression deformation of soil will be nonlinear and couldn't restored completely. It means that the soil is plastic in this stage.

The third stage, the piercing failure stage. When the vertical load is bigger than the ultimate force P_u, the soil will be sheared and damaged as the resistance of soil decline quickly and the subsidence deformation is irrecoverable.

Generally, the plastic critical force P_{cr} and the ultimate force P_u are not very obvious in the shear failure of soil. We can get an estimated values of them by soil compression experiments.

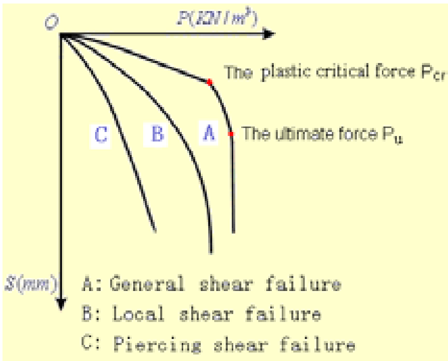

Fig. 1 P- S curve

2.2. Subsidence harms

According to the analysis of compression characteristic of soil, an analysis of subsidence harms is given, referred to the subsidence problems of civil structures. The subsidence harms of civil structures are mainly manifested in two aspects: one is structure damage, which is caused by differential basal soil deformation of subsidence. The soil is almost in the first or second compression deformation stages in this kind of damage. The other is basal soil damage. In this situation, the vertical forces acting on the base exceed the ultimate force P_u, the basal soil is pierced and the structure will have a very quick subsidence and accompanying structure damages. The soil is pierced and damaged in the third compression deformation stage. For example, the foundation of a barn is sliding failure as the internal storage of grain weight exceed the ultimate bearing capacity. This kind of damage is very dangerous and should be considered seriously.

3. Subsidence monitoring methods

The subsidence problem of offshore platform is the same with the civil engineering. Therefore, the subsidence harms of offshore platform can be divided into two aspects: on the one hand, the remarkable subsidence or differential subsidence of the piles caused the jacket with large deformations, which will induce the stress concentration, structure damage and other problems. On the other hand, the pile foundations suffered too much loads, which is overload. The basal soil was pierced and the platform will subside quickly. The platform will be damaged or capsized immediately. These can be summarized as the structural deformation requirement and the foundation bearing capability requirement.

It is obviously that the foundation bearing capability requirement must be met as the harms of it is much serious. The foundation bearing capability must be considered in the design process of the platforms. But the basal soil is unstable and the weight of the platforms are usually increasing. It has the possibility that the foundation bearing capability is not enough. Thus we can monitoring the total forces acting on the piles of the platforms, through which to protect platforms against the subsidence harms.

Generally, the first symptom of subsidence is the deformation of the structure which is induced by the subsidence or the differential settlement of the piles. If the deformation is acceptable and the subsidence is stable, the harms of subsidence will be very little. Thus we can monitoring the structures' deformations and evaluate the subsidence states, thought which to protect the platform against the subsidence harms.

Overview, we can monitoring the subsidence problem through the three points as follows:

3.1. Forces acting on the piles

The forces acting on the piles influence by the static weight of the platform and some dynamic force such as drilling load, lifting load and so on. Generally, it is difficult to get the changing of the forces acting on the piles of an offshore platform in field. In this paper, a novel method was applied to monitoring the forces acting on the piles which will be introduced in the following.

3.2. Differential settlement

A little symmetrical and stable subsidence is very normal and acceptable in civil engineering. But the differential settlement will induce structure damages and overturn. The differential settlement of the offshore platform is also dangerous and unacceptable. It is difficult to measure the absolute settlement of offshore platform in field, but it is easy to measure the differential settlement of the piles using some normal technology used in civil engineering.

3.3. Structural deformations

We also can measure the structural deformations induced by the subsidence，through which to evaluate the structure security and subsidence states. For the offshore platform, we can measure the strain responses of the structure or the tilt angles of the beams which are induced by the differential settlement.

4. Application

There is a six-legged jacket platform located in the northeastern area of Bohai Bay. In order to save the rental cost of drilling ship, it is designed with the drilling equipments and will drilling on the platform. The static weight of the platform, including the jacket, the topside, the drilling modules, the living building and other facilities, is very heavy. The drilling operation on the platform brings too much dynamic force acting on the platform legs too. In addition, the soil at the location of pile heads is very unstable as the support layer is the junction of sand layer and clay layer.

It is means that the basal soil of the platform is unstable, while the static weight and the dynamic forces are large and variable. These factors make the platform having a very high subsidence risk. Thus it is necessary to monitoring the subsidence states of the platform and evaluate the risk through the monitoring data. Furthermore, to give some suggestions about how to avoid or reduce the potential subsidence risk. We monitored the forces acting on the six piles, the differential settlement of the six legs and the structural deformations in field and evaluated the subsidence risk through the monitored data.

4.1. Field monitoring

Firstly, it is very hard to measure the forces acting on the piles directly through some normal force sensors, as it is impossible to install the force sensors between the piles and the soil. The piles will be compressed as the changes of the forces acting on it. The strain response of the pile is linear and sensitive. Thus we can monitoring the forces changing by measuring the strain responses of the piles. As shown in Fig 2, some FBG strain sensors were installed on the surface of the pile to monitoring the forces changing acting on it. Secondly, some differential settlement monitoring equipments were installed on the six piles as shown in Fig 3. Finally, some structure responses were monitored too. As shown in Fig 4, some FBG strain sensors were installed on the beams of the platform, which are sensitive to the strain responses induced by subsidence. Meanwhile some tiltmeters were also installed on the beams to monitoring the angles response if the subsidence were asymmetrical.

Fig. 2 FBG strain sensor installed on the pile leg

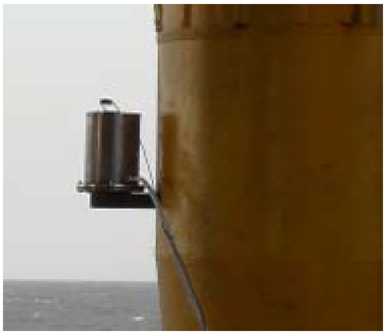

Fig. 3 Differential settlement monitoring equipment

4.2. Discussion

Some information was gained by the filed monitoring system, based on which, we can evaluate the subsidence states of this platform. Firstly, the monitored forces acting on the six piles are as shown in Fig 5. We can avoid the subsidence problem caused by the extreme forces through the forces monitoring and controlling. Secondly, the monitored differential settlement conditions are as shown in Fig 6. The differential settlements are stable and resumable. It is within the acceptable range. The measured strain responses of the beams are very little, therefore it isn't shown due to space reasons. The tilt angles of the beams are shown in Fig 7. It shown that the tilt angles are very little. The biggest changing are listed in the Table 1. it is very small and acceptable.

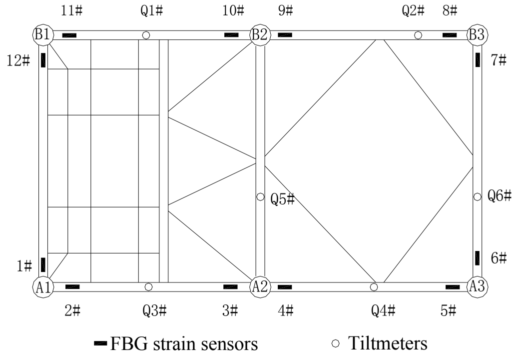

Fig. 4 Layout of the strain sensors and tiltmeters

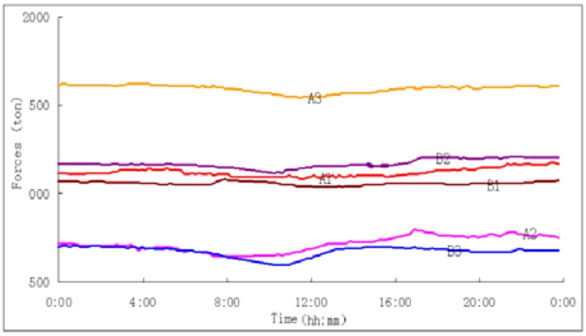

Fig. 5 Forces varieties of one day

Fig. 6 Differential settlement curves during the whole monitoring term

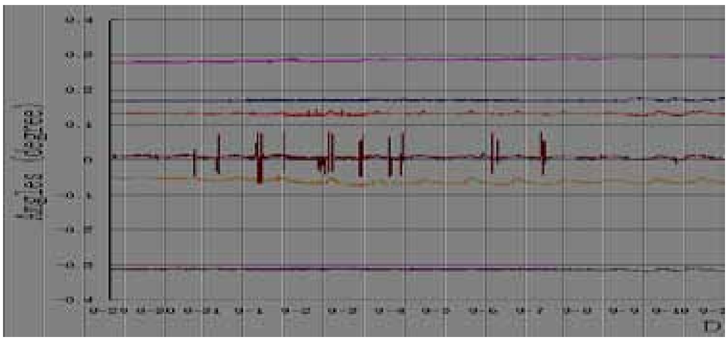

Fig. 7 varieties of the tiltmeters

Table 1 Angle varieties of the beams (degree)

No.	1	2	3	4	5	6
Angle changing	-0.01354	-0.003436	0.02863	-0.02761	-0.03906	0.02761

5. Conclusions

The subsidence problem is very normal in civil engineering. The offshore platforms are far away form the earth. It is hard to monitoring the subsidence problem as the civil engineering does on land. Some technologies, which are applied to monitoring the subsidence problem in abroad, are very complex and hard to get in China. In this paper, a simple and effective method is proposed to monitoring the subsidence problem of offshore platforms base on analyzing the compression characteristic of the soil. At last a real application is given and it is shown that the method is suitable for the subsidence monitoring of offshore platforms.

Acknowledgements

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