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INVESTIGATION OF JETTING PIPING SYSTEM IN THE SPUDCAN OF WIND TURBINE INSTALLATION JACK-UP VESSEL

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ABSTRACT: The offshore wind turbine in shallow water is installed by a self-elevated mobile unit which is usually referred to as jack-up barge or jack-up vessel. The jack-up vessel consists of a buoyant platform together with independent legs that can position the vessel above the water reducing external loadings for safe operation condition. The retrieval process of jack-up legs could be very difficult due to the high extraction resistance caused by soft soil. In soft clay, since the high suction force can be developed around the spudcan attached at the end of jack-up legs, a jetting system is required to break the suction to pull out the legs. It is important to design the jetting system with optimized piping arrangement to allow the easy operation. There are various factors to be considered in the design of jetting piping system since the level of embedment and the type of soil and pipe size and locations, etc. can affect the performance of the system. In this paper, the design of 500m^3/hr jetting system is introduced with PIPENET program analysis. Also the various consideration factors in the analysis are discussed.

Keywords: Jetting, spudcan, WTIV (Wind Turbine Installation Vessel), jack-up, bearing capacity, penetration, extraction

INTRODUCTION

Mobile jack-up barge or jack-up vessel have been used extensively in the offshore industry for offshore structure installation and drilling process. A jack-up unit consists of a buoyant hull, a number of legs and a lifting system that allows raising its hull over the surface of sea to provide a stable operation (Vazques et al. 2005).

Wind energy is one of the important alternative clean energy sources that will contribute to solve an energy problem and environment disruption. For this reason, wind energy industry is currently undergoing a period of rapid globalization and consolidation. Larger amounts and better wind speeds are available offshore compared to on land, so offshore wind power industry has established a notable place on the world energy market recently.

WTIV (Wind Turbine Installation Vessel) is newly designed mobile jack-up vessel which is purpose built for the requirements of the offshore wind turbine industry. WTIV is able to transport, assemble and install components, foundations and partly assembled turbines.

Jack-up legs and footings of WTIV could support the hull when WTIV is in the Elevated mode and provide stability to resist lateral environmental loads. After the installation of a wind turbine and prior to move, WTIV must extract its spudcan footings from the seabed. The jetting system at the spudcan aims to reduce the extraction resistance (Bienen et al. 2009).

The research presented in this paper aims to introduce the jetting system of WTIV and procedures of design the jetting piping systems. In this study, the commercial software PIPENET Vision 1.6 was used for design the jetting piping system.

SPUDCAN FOOTING

The purpose of spudcan is to increase the bearing capacity of footing system, and that can make stability during operations. And also, it is designed to spread the vertical load so that the WTIV does not sink too deeply into the seabed. The diameter of the spudcan is mostly ranges from about 5m to 20m (Yi et al. 2012).

Spudcan is generally designed to be conical and polygonal, circular or square in plane with sloping top and bottom (Okky et al. 2006).

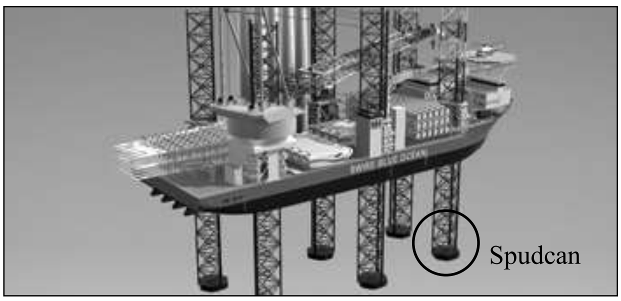

Fig. 1 Spudcan of WTIV (Swire Pacific Offshore Operations (Pte) Ltd)

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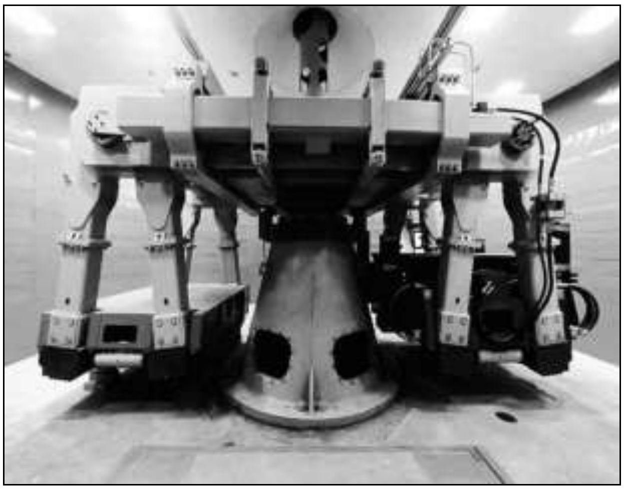

Fig. 2 Geotechnical Centrifuge Facility (The Hong Kong University of Science and Technology)

Centrifuge Modeling

To understand the behavior of spudcan footing, it is recommended that full scale geotechnical model tests be performed, for uncertainty of undrained soil behavior. However, in the test of spudcan footing to be performed on the real sea, there are several limitations as model size, environmental status, monitoring system, research funds, et cetera. The limitations of full scale geotechnical model test can be overcome and be recreated by centrifuge tests in which high pressure could be generated by increasing the self-weight of the soil by the ratio of the centrifuge acceleration. The effect on penetration and extraction of soil remoulding and consolidation, preloading could all be modeled in the centrifuge (Gaudin et at. 2011).

Many geotechnical studies of spudcan behavior have been performed using centrifuge modeling technique. Centrifuge modeling methods offer the approximate value of soil properties and loading conditions. Since centrifuge modeling methods have been used widely to investigate the behavior and performance of spudcan foundations. The experiments of spudcan footing have been developed through centrifuge modeling tests at the University of Western Australia and National University of Singapore. These research institutes investigate the spudcan footing and participate the compilation of the InSafeJIP which is industry guidelines for the installation and removal of jack-ups (Osborne et al. 2011).

Spudcan Penetration

The spudcan penetrates the seabed by self-weight of the WTIV, and then preloaded by water ballasting, as depicted in Fig.3 (b). Preloading is conducted by pumping seawater into the hull to increase self-weight of vessel. The preloading causes the deeper penetration of spudcan below the seabed before mobilizing sufficient bearing resistance. The vertical load of spudcan increases almost linearly with penetration depth. And the maximum penetration resistance is measured at the final penetration depth (Leung 2005).

The bearing resistance is determined by soil strength, embedment ratio (H/D), overburden pressure caused by soil backflow, etc. In this study, H is the embedded depth and D is the diameter of the spudcan. As changing the geometry as the spudcan penetrates the soil, contact area and soil strength changes. These changes affect the bearing resistance.

Spudcan Extraction

Upon completion of an installation of the wind turbine at a site, the WTIV may need to be relocated elsewhere. To extract the legs, hull buoyancy is generated by jacking down the hull into the water, as illustrated in Fig. 3 (d). The uplift force required to retrieve the legs from the seabed need to exceed the soil resistance. The uplift force is primarily governed by hull buoyancy and rack and pinion capacity of elevating system (Osborne et al. 2011).

The ultimate uplift capacity (extraction resistance) of the spudcan is typically expressed in terms of a breakout factor, which is a function of the structure shape, embedment depth, overburden pressure and the soil properties (Mehryar et al. 2002). Difficulty of leg withdraw is caused by a deeply embedded spudcan and a range of very soft soil conditions.

The leg extraction created immediate increases in pressures at the around of the spudcan. However, a more massive suction pressure developed at the spudcan base. This negative pore pressure at the bottom of the spudcan contributes to the extraction resistance. After that, the resistances become smaller due to breaking the suction at the interface between the soil and the base of the spudcan by water infiltration (Gaudin et al. 2011).

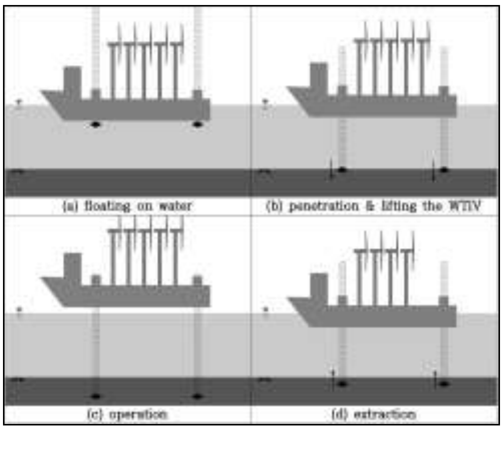

Fig. 3 Operation Procedure of WTIV

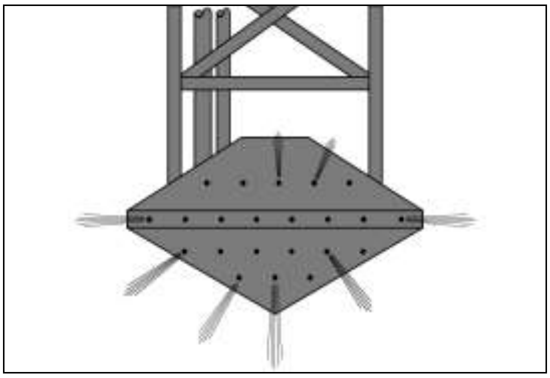

Fig. 4 Elevation View of the Universal WTIV Spudcan Showing Jetting Flow

JETTING SYSTEM

In a long time and deep penetration of spudcan at soft soil conditions, WTIV hull buoyancy and rack & pinion capacity may be insufficient to extract legs. To overcome limited buoyancy of the hull, spudcans are typically equipped with a water jetting system. Jetting nozzles are arranged in the top and bottom of the spudcan as shown in Fig. 4. Top jetting aims at remoulding the soil above the spudcan. On the other hand, bottom jetting is aimed to overcome the uplift-induced suction.

Pressure Drop Model

Pressure drop of jetting water occurs with frictional forces, caused by the resistance to flow, on a jetting fluid as it flows through the jetting pipe of about 40~100m. A jetting pipe containing a high relative roughness rating as well as pipe fittings and bents, surface roughness and other physical properties will affect the pressure drop.

Pressure loss due to friction and fittings can be found by comparing the theoretical results obtained using the Bernoulli Equation with those obtained in experiments. The frictional loss in pipes is described by Henri Darch (1803-1858) as the following:

$$P_{fric} = f \cdot \frac{L}{D} \cdot 2\rho u^2 \tag{1}$$

The pressure loss due to the difference in elevation is given by:

$$P_{elev} = \rho g Z \tag{2}$$

The pressure loss caused by the fittings is given by:

$$P_{fittings} = \frac{k\rho u^2}{2} \tag{3}$$

Table 1 Environment Information of Jetting

Parameter	Value [m]
Water depth	55
Penetration depth	20
Pump position (from sea level)	5
Spudcan height	5

Table 2 Summaries of the Jetting Pipe Condition

Pipe Specification	Pressure [KPa, G]	Flowrate [m^3/hr]	Node Condition
High Pressure	150	-	Input
	-	25	Output
Low Pressure	37.5	-	Input
	-	12.5	Output

Where D = internal diameter of pipe; L = pipe length; f = Fanning friction factor; u = fluid velocity; ρ = fluid density; g = acceleration of gravity; Z = change in elevation (PipeNet 2010).

A pump system makes a fluid move and control valves regulate flow and pressure in pipes. In addition to these, figuration of the spudcan, arrangement of nozzles and pipes affect the jetting performance.

Jetting Piping Design

Jetting pipe analyses were carried out using the commercial fluid-flow analysis software PIPENET VISION Standard Module.

The environmental condition of jetting is tabulated in Table 1. The total elevation (from jetting pump to spudcan bottom) of jetting pipe is about 85m. JIS1990Steel_160 for the jetting pipe was applied in the analysis and internal diameters of 125, 200, 250 and 300mm for each position were considered. The applied roughness of jetting pipe is 0.04572mm.

Jetting pipes are compartmentalized into two high injection pressure pipes and two low injection pressure pipes. Each high and low injection pressure pipe is composed of eight nozzles and four nozzles. High injection pressure nozzles located at the spudcan invert, and low injection pressure nozzles are for the spudcan top side.

The high pressure input condition of 150KPa and the low pressure input condition of 37.5KPa was applied. In addition, each high jetting and low jetting nozzle was set to 25m^3/hr and 12.5 m^3/hr flow rate as shown in Table 2. The applied total jetting flow rate is 500m^3/hr.

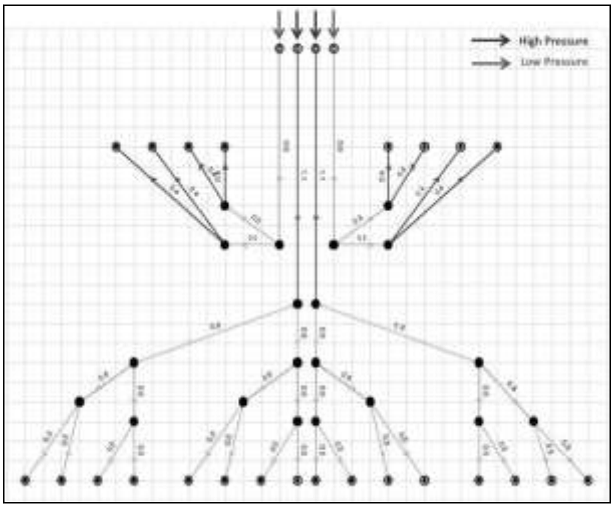

Fig. 5 Flux Model of Pipe Flow Analysis

Fig. 5 shows the result of flow velocity variation. High pressure inlet velocity of 1.1m/s was dropped to 0.5m/s at nozzles and also, low pressure inlet velocity of 0.6m/s was dropped to 0.4m/s. Pressure at the nozzles was increase to about 988Kpa despite flow velocity drop. This is because of about 80m difference of elevation between inlet and nozzle. There was no flow reversal because nozzle injection pressure is higher than sub-seabed pressure and minor flux reduction.

CONCLUSION

In this study, the operation procedure of WTIV and spudcan footing behavior is reviewed. And jetting piping system considering the pressure drop model was analyzed.

Centrifuge modeling can accurately reproduce stress condition of the soil in-situ, allowing behavior and performance of spudcan foundations to be investigated.

Bearing capacity of the spudcan is determined by soil strength, geometry of spudcan, duration and depth of embedment.

When the WTIV is to be relocated, legs are required to be retrieved by jacking down. To reduce the pull-out resistance during extraction, a jetting system is equipped at spudcan. The reduction of extraction resistance is proportional to the jetting flow rate.

In order to design the jetting system, pressure drop constituent such as pipe configuration, nozzle, control valve and pump should be considered. The jetting piping system was analyzed using PIPENET Standard Module.

Offshore wind turbine industry is forecast to grow, and thus the demand for using WTIV is expected to grow. Therefore understanding of spudcan footing behavior and jetting system is necessary to operate the WTIV safely.

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