Applied Ocean Research 59 (2016) 24–37

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Design of a novel installation device for a subsea production system

Yuguang Cao[a,*], Xueyang Hu[a], Shihua Zhang[b], Songsen Xu[b], Jungin Lee[a], Jiancheng Yu[c]

[a] Province Key Laboratory of Safety of Oil & Gas Storage and Transportation, China University of Petroleum, Qingdao, China
[b] Driling Technology Institute of Shengli Petroleum Bureau, Dongying, China
[c] State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang, China

ARTICLE INFO

Article history:
Received 24 June 2015
Received in revised form 5 May 2016
Accepted 11 May 2016
Available online 27 May 2016

Keywords:
Subsea production system
Installation method
Floating installation device
Theoretical computation
Numerical simulation

ABSTRACT

Subsea production systems (SPSs) have dominated the exploration of deep-sea oil and gas fields because of their economic superiority. SPS is a high-investment and high-risk technology. A floating installation device (FID) and an installation method for the SPS using this device were designed in this study. The device is made of buoyant materials, allowing both the SPS and the FID to be kept in a suspended state. Thus, the restriction caused by the great weight of the SPS can be avoided. The dynamic response of the chain system and FID was analysed according to environmental loads and material characteristics. The feasibility of the design was validated through numerical simulation and theoretical computation.

1. Introduction

The subsea production system (SPS) consists of several typical subsystems, including a wellhead, a Christmas tree, a manifold, a bridge pipe and so on. This system has dominated the exploration of deep-sea oil and gas fields because of its advantages of high efficiency and a wide application range. The installation of the SPS is difficult because of the complexity of the ocean environment and the heavy weight of the system. At present, the mainstream installation methods for the SPS include the traditional installation methods [1,2], the sheave installation method (SIM) [3–7], the pendulous installation method (PIM) [8–10], the pencil buoy method (PBM) [11,12], the heave compensated landing system (HCLS) [13] and the subsea deployment system (SDS) [14].

The traditional installation methods, which use a single wire or drilling string to deploy small and medium subsea structures, mainly include two methods: the drill-strings installation method (DSIM) and the winch-wire installation method (WWIM). In the DSIM, the SPS is connected to a drilling string from large drilling platforms and can be lowered and installed by paying out the drilling string. Petrobras used a large drilling system to install a manifold in 940 m water depth in August 2001. In contrast to the DSIM, in the WWIM, the SPS is normally lifted off from the deck of the heavy lift vessel using a ship crane, and then lowered by paying out the winch wire. In December 1995, a 412 t production manifold was installed in 620 m water depth at the Albacora field. The traditional installation methods are conventional, simple and mature but currently are rarely used to install the SPS, mainly because of the limited lifting capability of the drilling platforms and vessels.

The SIM is based on the two-fall configuration of a conventional deployment system. The major difference from the traditional methods is to relocate the fixed point for the dead end of the deployment rope from the same installation vessel to another vessel. A semisubmersible (SS) and two deployment vessels are used in this method. However, this method also has drawbacks. Three deployment vessels mean expensive day rates and complex operation. Therefore, numerical simulation and field-testing are necessary in this method.

The PIM is a non-conventional method originally developed by Petrobras to successfully install a 280 t large SPS in water depth of 1900 m. The PIM uses a conventional steel wire winch system as a launch line to launch and install the SPS in a pendulous motion. Due to the complex operation in this method, hydrodynamic instability may arise during launch operation, and the strict requirements for the ocean environment limit its development.

The PBM is a subsurface transportation and installation method developed by Aker Solutions. The SPS is suspended from a pencil-shaped buoy during the wet tow process. Upon arrival at the installation site, the towing wire is winched in, and the buoy is disconnected. Similarly to the WWIM, the lowering operation is a standard offshore operation, and thus the crane lifting capability

* Corresponding author.
E-mail address: cao_yuguang@qq.com (Y. Cao).

http://dx.doi.org/10.1016/j.apor.2016.05.006
0141-1187/

Nomenclature

b	Vibration amplitude of the lowering point
c	Damping coefficient
C_D	Drag coefficient of the weight-balancing chain
C_M	Inertia coefficient of the weight-balancing chain
d	Diameter of unit i-1
du_i/dt	Water particle acceleration caused by wave
D	Length of the weight-balancing chain above the water surface
D_w	Ocean depth
F_i	Drag force and inertia force acting on unit i-1 caused by wave and ocean currents
F_{xi}	Force in the X-axis direction acting on node i
F_{zi}	Force in the Z-axis direction acting on node i
G_i	Submerged weight of unit i-1
G_m	Submerged weight of the steel clump chain
H	Wave height
k	Equivalent stiffness of the chain
l	Length of unit i-1
L	Length of the weight-balancing chain under the water surface
M	Mass of the weight-balancing chain
M_e	Mass of the vibration system
n	Number of differential segments
p	Natural frequency
T	Wave period
T_d	Dynamic load along the chain
T_s	Static load along the chain
$T(t)$	Axial tension along the chain
u_i	Water particle velocity caused by wave
v_i	Water particle velocity caused by current
w_w	Submerged weight per unit length
X_L	Lateral displacement of the lower end of the chain
x_i	Lateral displacement of node i in the local coordinate system
z	Heave motion of the lower end
z_0	Heave motion of the lowering point
β_d	Amplification factor
ε_d	Initial phase
λ	Ocean wave length
ρ_w	Density of sea water
γ	Frequency ratio
ξ	Damping ratio
ω	Disturbance frequency

also limits its development. This method is ideal for long-distance and harsh-environment transportation.

The HCLS is based on a specific chain and buoy system and is similar to the PBM. The major difference is that the buoy is used in the installation process. The HCLS decouples the vessel motion from the payload by supporting the payload from the buoy, thus greatly reducing the impact of the vessel motion on the payload motion and the need for large offshore vessels. The HCLS also requires a large deck to transport the SPS because of the dimensions of the SPS.

The SDS is a method of installing large subsea structures without a heavy lift vessel. It uses a subsea deployment vehicle (SDV), which consists of solid buoyancy modules mounted on structural steel frames, to support the SPS during transportation, positioning and installation. This method effectively dampens the vertical motions, resulting in negligible dynamic response and a soft landing because the assembly of the SDV and SPS is slightly buoyant in seawater.

The maximum installation depth can reach 3000 m using the aforementioned methods, but the rental fees for installation technologies and equipment are always very expensive. In addition, the increasing weight of the system challenges the crane capacity of the vessel and the ultimate strength of the lifting pipe.

The FID developed in this paper is an affordable and available alternative that allows the use of a low-cost lifting vessel. The SPS is not supported directly by the vessel but instead by the FID. The assembly of the FID and SPS is transported to the site using a wet tow, which greatly reduces the effect of the surface environment. No special tooling is required in this method, which is therefore low-cost. Dynamic response analysis was applied to calculate the lateral displacement and axial tension along the weight-balancing chain by theoretical computation and numerical simulation. After comparing the results of the main bearing carrier with the results of other mainstream methods, the advantages and features of this design were analysed. In addition, a single-tug installation system was established using AQWA, and dynamic response was simulated and calculated for the system in the process of set down. The tension along the ballasting control chain and motions of the FID were modelled to analyse the stability of the assembly of FID and SPS.

2. FID structure design

Various deepwater installation methods have been developed to tackle the three major interrelated challenges, crane lifting capacity, dynamic responses to environmental conditions and installation cost [6,10,11]. The main factor is the overall dimensions of the SPS to be installed. The dimensions often limit the practical crane capacity significantly and require a large deck to transport the SPS, resulting in an expensive day rate. The FID was designed to solve the above challenges and meet the requirements of deploying a large SPS in deep water.

2.1. Main structure

The concept of the designed method originated from the PBM. The new method utilises an FID to support the SPS in the transportation and installation process. The device is mainly made of solid buoyant material, which has low density (lower than water), high compressive strength, a low water absorption rate and other properties. Thus, the transportation can be a wet tow process, and the need for a large deck space is eliminated, which is similar to the PBM. Fig. 1 shows a cross-section view of the FID. Fig. 2 shows the 3D schematic of the assembly of the FID and the SPS. The main body of the FID consists of the following components: the floating body, top lugs, lateral lugs, bottom lugs and fixed poles. The shape of the FID is mostly cylindrical with conical upper and lower ends, which can reduce flow resistance in the wet tow process. Lugs are designed on the top, sides and bottom of the FID to connect different chains. Three hydraulic release shackles are used to connect the three slings to the top rings on the SPS. The hydraulic release shackle is a remote operated vehicle (ROV)-operable shackle. The other ends of the slings are connected to the bottom lugs on the FID. The fixed poles on the FID that pass through the fixed rings can prevent the SPS from experiencing excessive lateral displacement and rotation. The FID can provide buoyancy because of the solid buoyant material, and the buoyancy is sufficient to render the assembly of FID and SPS slightly positively buoyant. Thus, the assembly can be transported to the site using a submerged tow, thereby avoiding the effects of the surface environment as well as the need for scarce specialized deepwater installation vessels or formidably expensive drilling rigs, making this approach cost-effective and much less sensitive to weather conditions than conventional installation.