Applied Ocean Research 77 (2018) 34–44

Contents lists available at ScienceDirect

Applied Ocean Research

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

A dynamic model to evaluate the influence of the laying or retrieval speed on the installation and recovery of subsea equipment

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ARTICLE INFO

Keywords:
Subsea equipment installation
Subsea engineering
Offshore engineering
Cable dynamics
Nonlinear dynamics
Heavy-lifting

ABSTRACT

A new model for the dynamics of a cable-mass system representing the installation or retrieval of subsea equipment is analyzed. It considers a one-degree of freedom system, which is able to account for the variation of the cable's length during the time, simulating the equipment laying or recovering process. Also, the cable's mass is included in the analysis and the hydrodynamic forces are modeled by the Morison's equation. The resulting nonlinear equation of motion is integrated over the time domain via a predictor-corrector Newmark β-method. Firstly, the proposed model is compared with an Orcaflex model on fixed and variable length scenarios. The results show that the proposed model give accurate solutions in comparison with the finite element model through all the depths evaluated, even at zones where superharmonic response occurs. Secondly, the influence of payout speed on the dynamics of the system is assessed. Here, the system presents a variation on the static and dynamic forces, especially at the resonance zone. Finally, an operational weather window is generated for a specific case, which shows that the acceptable sea states change depending on the laying or retrieval speed considered. This highlights the importance of using models that account for the payout speed when analyzing subsea equipment installation and retrieval operations.

1. Introduction

Subsea production systems have been used in offshore oil production for the past fifty years. One of the most costing activities to implement a subsea layout is the installation of equipment on the seafloor, mainly due to the high daily costs of dedicated vessels used on these operations. The two main approaches considered to reduce these costs, preserving the safety requirements, are the development of new installation methods, and the improvement of the methodologies to analyze these operations.

Regarding the development of new installation methods, the first ones considered the use of a drilling rig to deploy the equipment on the seafloor. This procedure is usually expensive and subjected to tight schedule restrictions since the main task of these rigs is the drilling of subsea wells. To overcome this challenge some new installation procedures have been proposed. Roveri et al. [1] described the installation of a manifold by a multiple slings technique. They showed that this method was efficient and cheaper than the traditional ones on their application. Further, Nelson et al. [2] proposed the use of buoy-chain device in-line with the hardware to be deployed to reduce the dynamic loads on the system. Another innovative solution is known as the pendulous installation method [3–5]. This procedure enables the use of low-cost support vessels to install heavy equipment in ultra-deepwater. Great effort [6–9] was also made to qualify and provide an installation system based on synthetic cables. This system is of huge value as the increase of the cable's mass tends to lead to prohibitive weather windows on ultra-deepwater. More recently, some authors [10–12] described a method in which the equipment is assembled to a submerged floating device in sheltered waters and then transported in a towing operation until the installation location. Since the equipment is not directly connected to the vessel in this scenario, the operation presents lower weather restrictions. Lastly, a review of the available methods to install subsea equipment is described by [13–15].

On the other hand, the improvement of the analysis methodologies is useful since it allows the industry to have more accurate solutions regarding the system's dynamics, which leads to wider installation windows preserving the safety requirements. The firsts studies [16–18] about the deployment of subsea loads considered analytical approaches, linearizing the drag force acting on the equipment and solving the resulting equations in the frequency domain. Later, some authors [18–21] considered systems which were solved in the time domain, accounting for the nonlinear drag forces and the possibility of

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https://doi.org/10.1016/j.apor.2018.05.001
Received 13 January 2018; Received in revised form 19 April 2018; Accepted 1 May 2018

Nomenclature

A	Cross-section area of the cable
A_p	Vertical projected area of the equipment
C_d	Drag coefficient of the equipment
E	Elastic modulus of the cable
F_{static}	Static force on the cable
g	Gravity acceleration
H_s	Significant height
$h(t)$	Function for the movement of the vessel at the lifting point
ℓ	Length of the cable from the equipment to a given point
L	Full suspended length of the cable
M_{add}	Added mass
M_{eq}	Mass of the equipment
m'	Linear mass of the cable
w	Displacement of the equipment
w_0	Displacement of the top of the cable
w_ℓ	Displacement of a material point within the cable
ρ	Specific mass of the water
$\mathbb{Q}$	Nonconservative generalized forces
SWL	Safe working load
T_p	Peak period
$\mathbb{T}$	Kinetic energy
	Time
$\mathbb{V}$	Potential energy
V	Volume of the equipment
$V_c(t)$	Function for the payout/retrieval speed
$\dot{}$	First derivative over the time domain
$\ddot{}$	Second derivative over the time domain
$\lvert\ \rvert$	Absolute value of a variable

predicting snap loads on the cable. While these works were focused only on the dynamics of a suspended cable, Kopsov and Sandvik [22] detailed all the steps that should be addressed in an installation analysis: lifting from the deck, lowering through the splash zone, lowering into deepwater and landing on the seabed. More recently, fluid-structure interaction models have been used [23–26] to predict the dynamics of the equipment in the wave zone. Although this tends to lead to more realist results, the computational cost is somewhat prohibitive. Finally, as a general guide, the recommended practice DNV-RP-H103 [27] provides simplified models for all the installation analysis steps, guidance for choosing hydrodynamic coefficients, and recommendations on how to use nonlinear dynamic models.

The lowering into deepwater is one of the critical steps to be analyzed when the final installation depth is high. In this case, the cable-equipment system may achieve a resonance regime due to the motion induced by the ocean waves. The common feature of the traditionally used models to analyze this step [16–22,27] is that the equipment is considered to be placed at a given depth and the cable has fixed suspended length. Therefore, to perform a full installation analysis, it is necessary to run several simulations with the equipment positioned at different depths. This procedure is considered valid according to the recommended practice DNV-RP-H103 [27]; however, it does not take into account the influence that the laying or retrieval speed might have on the dynamics of the system and on the operational weather window.

Even though these models do not consider the influence of the payout speed on the dynamics of the system, some works have already been presented dealing with this effect. The models proposed by [28–31] focused their efforts on the installation of submarine cables (such as communication or control cables); Wang et al. [32] considered a finite element model to analyze an underwater cable with time-dependent length, while Hu et al. [33] modeled the dynamics of a rigid riser with variable length during the installation of a subsea production tree. Outside the subsea area, Terumichi et al. [34] presented a model for the analysis of a string with variable length representing an elevator system; Moustafa et al. [35] dealt with the dynamics of overhead cranes during the load hoisting or lowering; and Du et al. [36] presented a model for the analysis of variable length cables to be used on large scale radio telescopes. Further, the version 10.2 of the commercial software Orcaflex [37], which was released in 2017, introduced the possibility of line feeding, enabling the users to analyze cables being laid or hauled.

Based on the works presented above, two main gaps may be pointed out regarding the methodologies to analyze the installation and recovery of subsea equipment. The first one is the lack of a simple model that is able to account for the influence of the payout speed on the dynamics of the system during the laying or recovery process. The existents models that deal with the payout speed [28–37] consider discretized systems, which take longer times to run the required simulations to construct a complete operational weather window. This is a crucial point, especially if an analysis is needed to be run aboard the vessel during the operation. The second one is the absence of studies presenting results of how the dynamics of the installation or recovery operation is affected by the payout speed, since the aforementioned works focused their results on the validation of the method or on different applications.

Consequently, this paper presents two main objectives: (1) to propose a simple model suitable to analyze subsea equipment installation and retrieval operations, which is able to account for the variation of the cable's length during the time, simulating the equipment laying or recovering process, and (2) to present results regarding the influence of the payout speed on the dynamics of the system and on the operational weather window.

The proposed model is based on a one-degree of freedom system, in a similar manner as described by Niedzwecki and Thampi [18]. However, it includes the possibility of varying the suspended length of the cable throughout time, and it considers the drag force on its nonlinear form. This model is then compared with the results presented by Orcaflex, in order to assess its accuracy on fixed and variable cable's length scenarios. Finally, the model is used to predict the influence of the payout speed on the dynamics of the system, and on the operational weather window for installation and retrieval operations.

2. Variable length cable-equipment model

Previous work has shown that in the absence of time-varying currents or large horizontal excursions of the vessel, the ship and the equipment are only coupled vertically. Therefore, a one-dimensional model is sufficient to represent the system [26]. Further, the system is considered to have one degree of freedom, which is the vertical displacement of the equipment.

It is also considered that the dynamics of the vessel is uncoupled from the dynamics of the cable-mass system. This assumption is normally acceptable and will give conservative results, as the object in most cases tends to reduce the vertical crane tip motion [27].

The mass of the cable is included in the analysis, and its suspended length is modeled as variable throughout time. Besides, a linear stress-strain relation and an elastic behavior are considered for the cable. Consequently, snap loads are not possible to be predicted by the proposed model, and only positive values for the efforts on the cable should be considered as valid results.

Fig. 1 represents the proposed model. The displacement of the top of the cable and the displacement of the equipment are respectively denoted by w_0 and w. As a simplification, it is considered that the cable is fully submerged, and the hydrodynamics forces act only at the equipment. These assumptions are usually taken for one-degree of freedom